



CONFERENCIA
NACIONAL SOBRE
PALMA DE ACEITE

Un encuentro para vivir el
conocimiento e impulsar
la agroindustria

La sostenibilidad de la bioenergía
derivada de los sectores
agroindustriales colombianos de
palma y azúcar en un contexto de
transición energética

Edgar Fernando Castillo
Ph. D., M. Sc., Ingeniero Químico



35
AÑOS



Villavicencio, Parque Las Malocas

22 al 24
de septiembre

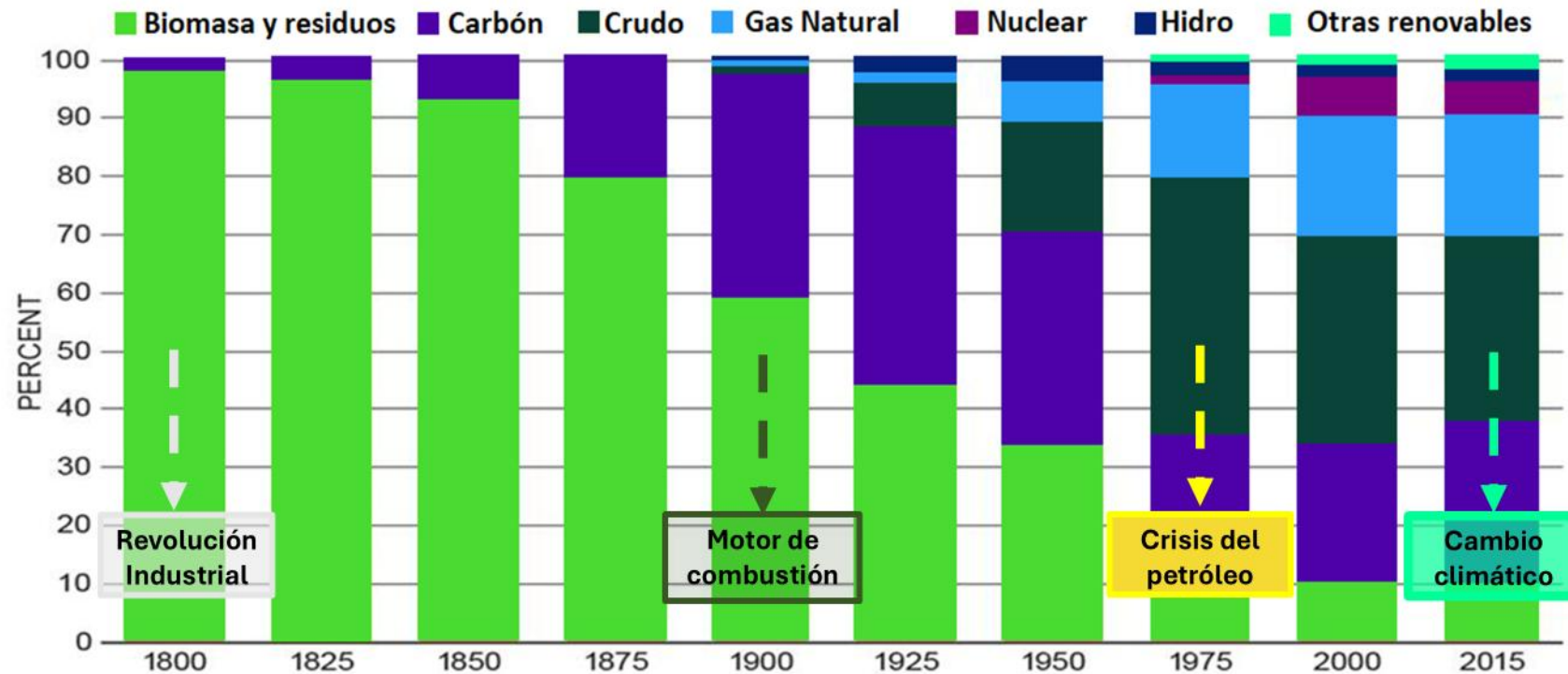
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26

CONTENIDO

- ✓ **Contexto de la transición energética a nivel mundial**
- ✓ **Sistema de transformación de energía**
- ✓ **La biomasa en el contexto renovable**
- ✓ **Oportunidades y limitantes de la bioenergía (electricidad, biocombustibles, olefinas)**
- ✓ **Sector azúcar y Sector palma**
- ✓ **Caso de estudio: SAF**
- ✓ **Los combustibles sintéticos.**

La actual transición energética tiene antecedentes...

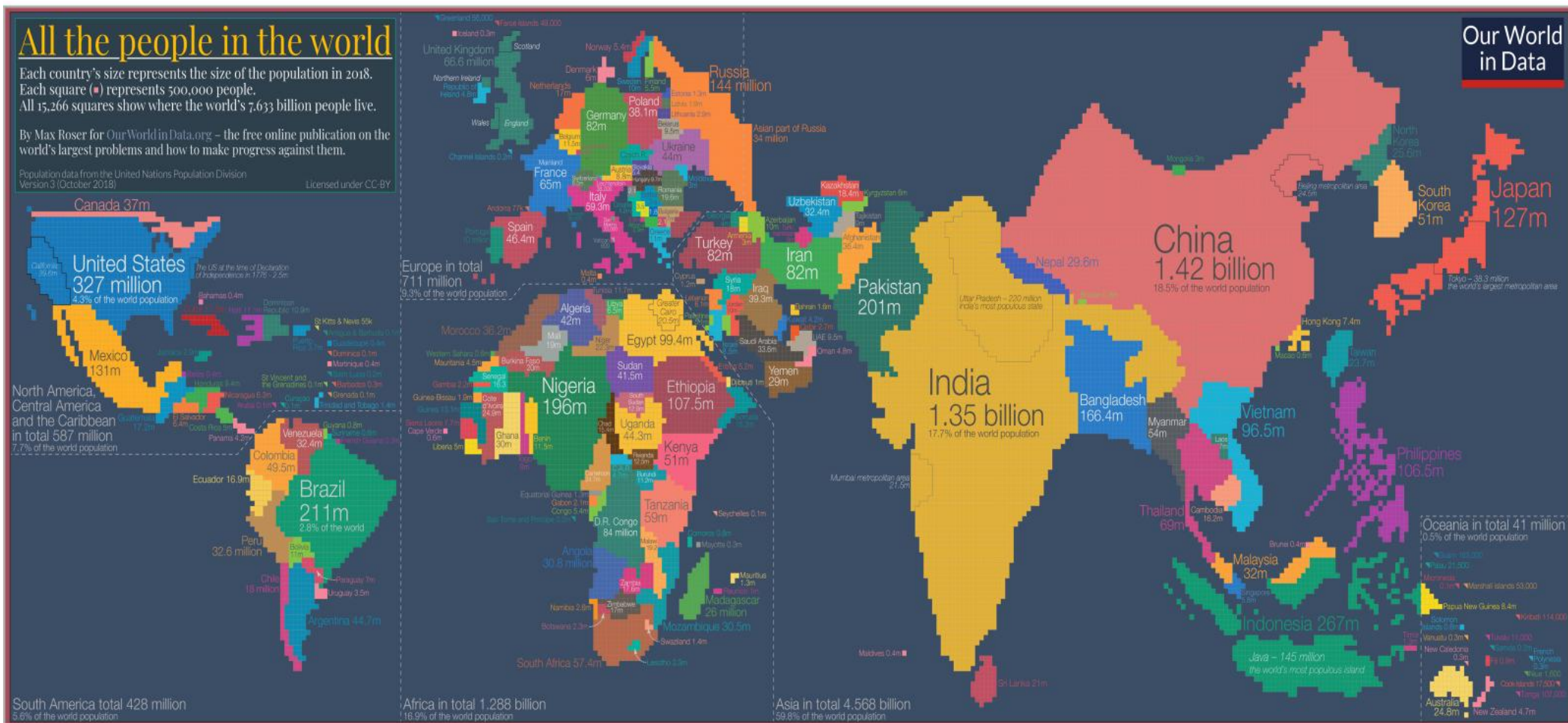
Demanda mundial de energía primaria por tipo



Fuente: Resources for the Future (2019). Global Energy Outlook data tool.
Accessed via www.rff.org/geo

All the people in the world

By Max Roser for OurWorldinData.org – the free online publication on the world's largest problems and how to make progress against them.



Puntuaciones regionales e información clave: puntuaciones medias por grupos

65.2

Average score

🌱 14% 🏠 34%

☁️ 31%

Advanced economies

Over the past decade, the ETI scores of advanced economies improved steadily by 11%, led by the Nordic region. All advanced economies have been able to achieve 100% access to electricity and develop reliable energy systems, but suffered greatly on affordability because of high energy prices in the past three years. The group made tremendous advances on regulatory policies, infrastructure, human capital and financial investment, but lags on innovation where it could make pioneering developments.

54.6

Average score

🌱 3% 🏠 7%

☁️ 7%

Commonwealth of Independent States

The Commonwealth of Independent States witnessed an improvement in aggregate ETI scores by 11% over the past decade. But its system performance scores declined last year with an increase in subsidies and high gas prices. In the last 10 years, the group witnessed a jump of 22% in transition readiness scores, but that was limited to only 1.5% in the last year. The contribution to the large increase comes from significant improvement within clean energy jobs over the decade, providing hope and employment for a prepared green workforce. In the future, the group should focus on improving energy affordability for its consumers and reducing fuel subsidies, which grew by a huge 17% in the last year.

53.4

Average score

🌱 51% 🏠 39%

☁️ 46%

Emerging and developing Asia

Emerging and developing Asia, home to the populous countries of India and China, improved its ETI scores by 12% in the last decade. While this is one of two groups that have made greater than 10% improvement on the equitable dimension in the past decade, it increased fuel subsidies dramatically in the last year. Performance on the sustainable dimension remains flat with worsening carbon intensity. The group should focus on improving both security and sustainability given the energy demand per capita is projected to double by 2050. With a 28% increase in enabling environment scores, the region has strengthened its policy framework and financing environment. Focusing on innovation, adding more renewable capacity and diversifying the energy mix by moving away from fossil fuels can accelerate the transition for this group.

54.8

Average score

🌱 9% 🏠 6%

☁️ 4%

Latin America and the Caribbean

This group showed the slowest gain, with ETI scores increasing 5% over the last decade. The group leads on the sustainable dimension due to heavy use of hydroelectric power. But surprisingly, its investment in renewables scores declined by 65% over 10 years. The Renewables in Latin America and the Caribbean initiative, created at the end of 2019, aims to fulfil 70% of the group's electric energy consumption with renewables by 2030. Latin America produces several minerals necessary for clean energy technologies and could develop its firmly set mining sector to diversify into new minerals. To unlock further improvements, the group can strengthen its enabling environment, where again it showed a modest growth of just 8% in 10 years. It should focus on leveraging its advantage in natural resources to boost innovation, promoting public-private partnerships for better credit access, and introducing environmental tax reforms for long-term benefits.

49.2

Average score

🌱 11% 🏠 4%

☁️ 2%

Sub-Saharan Africa

Sub-Saharan Africa's energy transition growth of 11% has been one of the most promising in the last decade, and it is the strongest performer of all groups on the sustainable dimension. On certain parameters, such as scores for regulatory indicators for sustainable energy (RISE), creation of green jobs, and regulation and political commitment, it was also the best performer. Sub-Saharan Africa showed the maximum gain of 18% on scores on the equitable dimension in the past decade, but recent trends show a slowdown, about which the region should be cautious. It needs to focus on improving its energy mix and harnessing its abundance of natural resources to transition faster to a low-carbon economy. The group can do so by attracting global investments, leveraging public-private partnerships and strengthening its infrastructure.

50.5

Average score

🌱 9% 🏠 8%

☁️ 7%

Middle East, North Africa and Pakistan

The scores for the Middle East and North Africa and Pakistan grew by 8% in the last decade and have been flat for the past three years, where the heavy reliance on oil revenues continues to pose challenges on the path to a sustainable energy transition. Even though subsidy scores improved by 200% – the maximum for any group – they plunged 33% in the last year alone. This group needs to catch up on sustainable scores by reducing energy intensity and share of GHG emissions. On transition readiness, it was at par with other groups with a 20% gain over the last 10 years but showed the maximum decline on innovation. Directing its investments towards development of environmental technologies can help on this front.

57.7

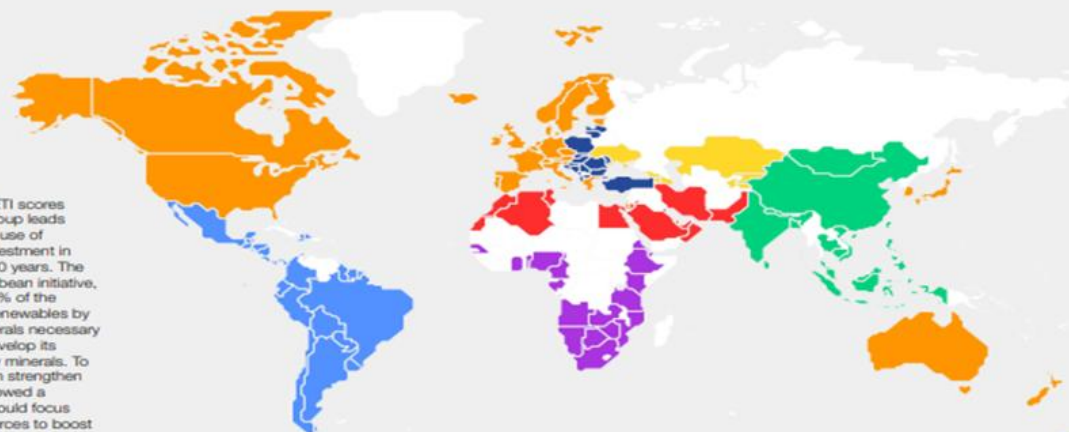
Average score

🌱 3% 🏠 3%

☁️ 3%

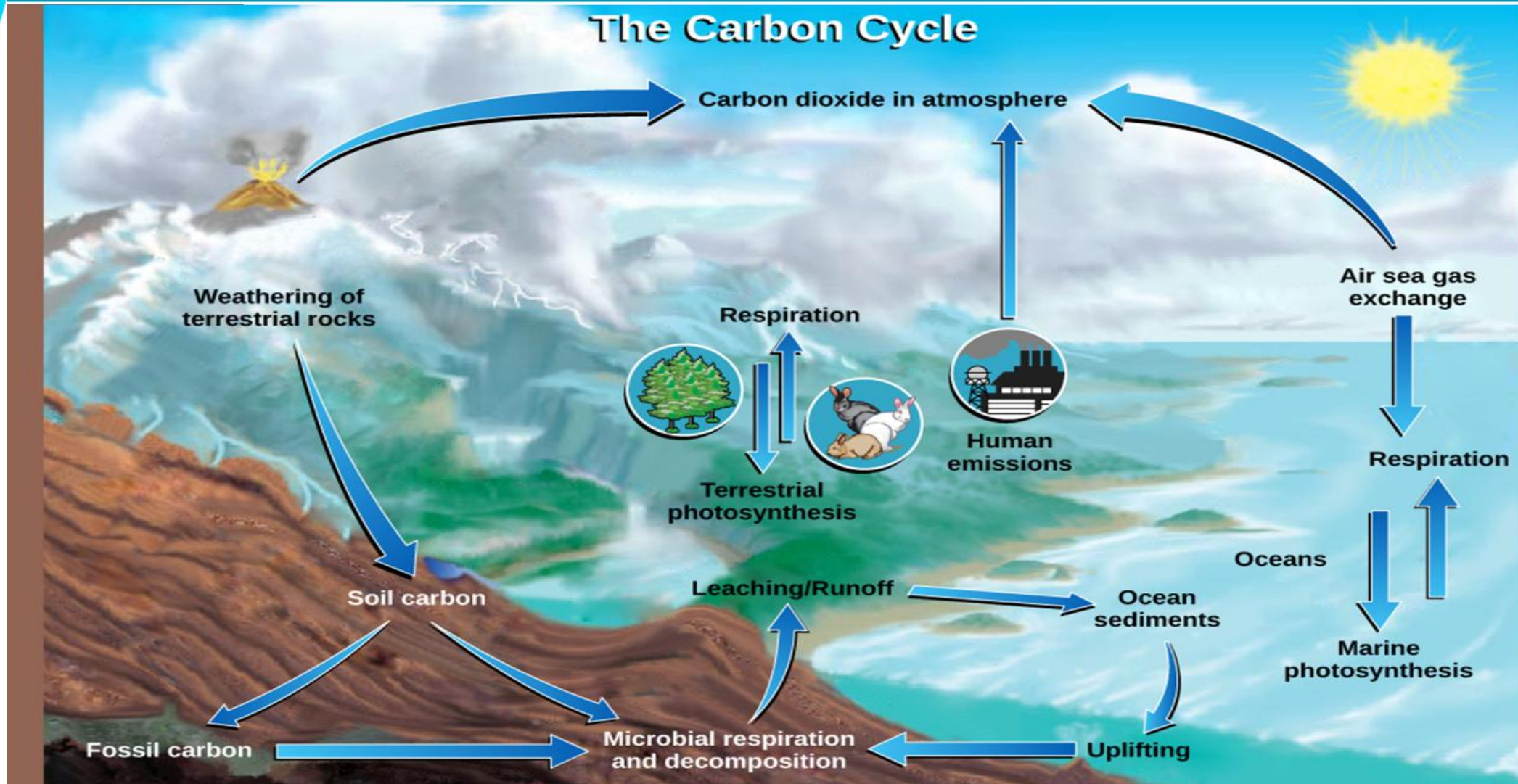
Emerging and developing Europe

This group showed the most promising growth, increasing ETI scores by 13% over the past decade. But problems mounted last year as the energy crisis hit the group the hardest, leading to a decline in scores. The wholesale prices of electricity and gas have surged 15-fold since the beginning of 2021, severely affecting households and businesses. The group performed well on transition readiness, with a gain of 22% in its scores. In the past three years, the group significantly improved on adding clean energy jobs and on investments in renewables, which was reflected in its renewable capacity addition scores. In the short term, these countries need to focus on reducing energy demand and increasing affordability for their consumers, while continuing to strengthen their readiness for the future.

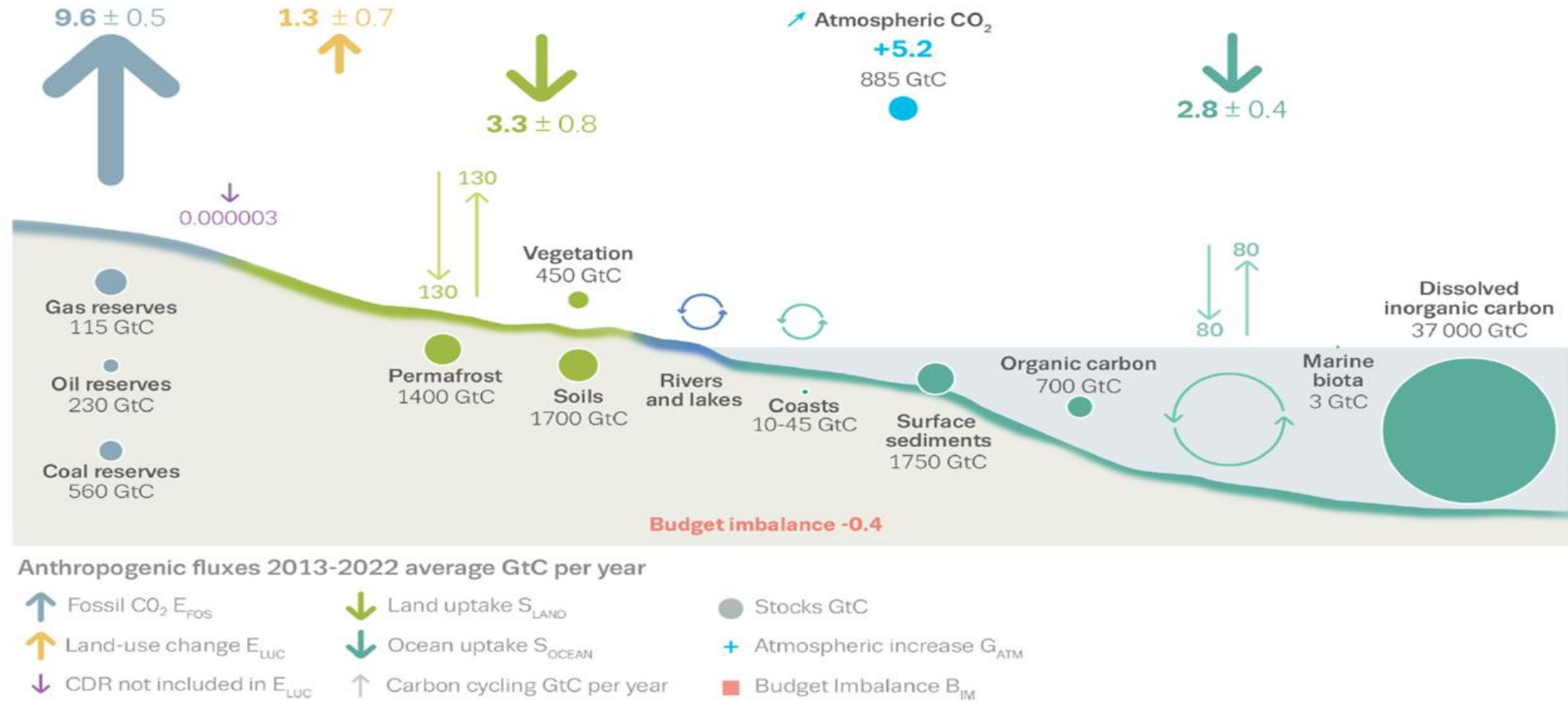


Fuente: Fostering Effective Energy Transition, 2023 Edition. INSIGHTREPORT, JUNE 2023

La energía fósil afecta el ciclo natural del carbono

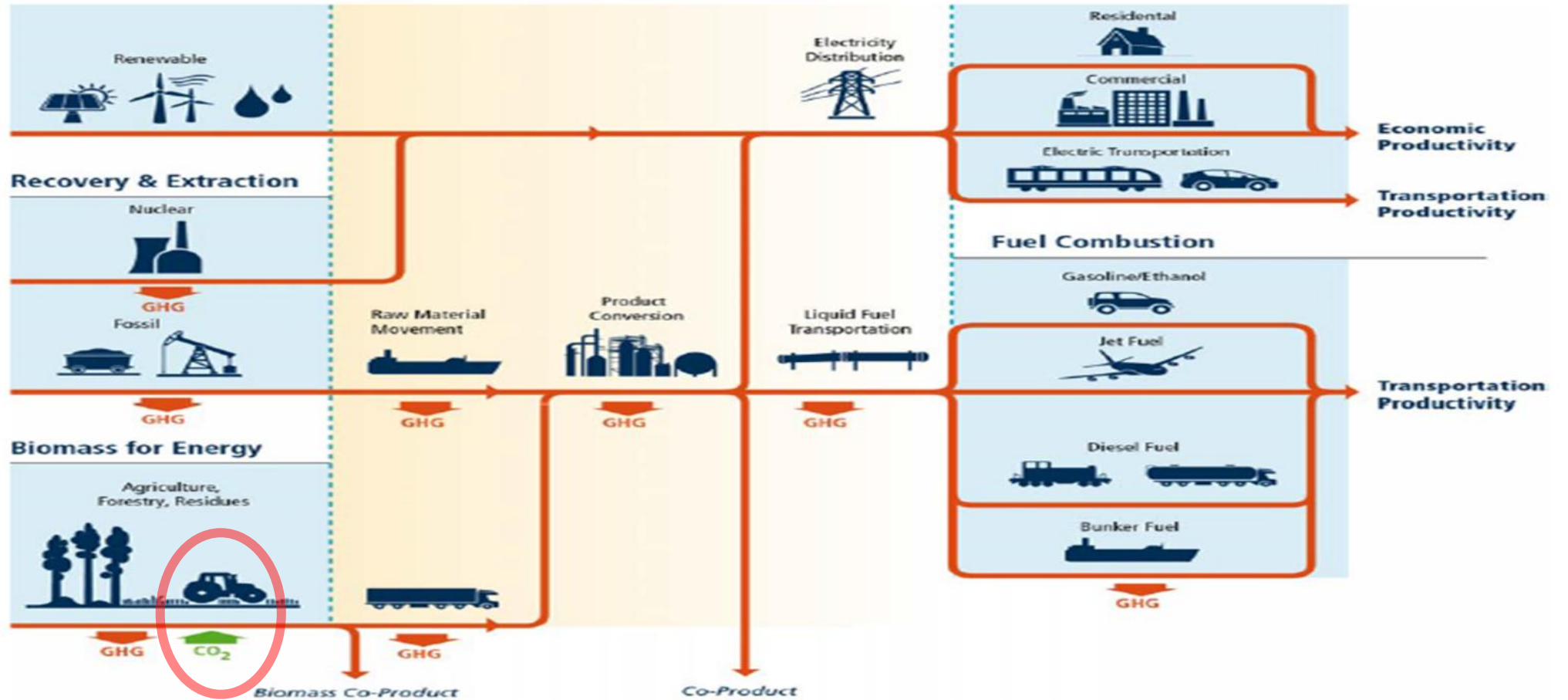


The global carbon cycle



Fuente: Carbon Budget 2023. Earth Syst. Sci. Data, 15, 5301–5369, 2023
<https://doi.org/10.5194/essd-15-5301-2023>

Sistema ilustrativo de la producción de energía



Fuente: IPCC SRREN report 2011

.....*La fotosíntesis puede seguir diferentes mecanismos.....*

Las plantas C3 se caracterizan por el compuesto inicial que se forma durante su proceso de fijación de carbono. La primera molécula orgánica estable producida es un compuesto de tres carbonos llamado 3-fosfoglicerato (3-PGA)

Las plantas C3 generalmente prosperan en entornos con temperaturas más frescas, abundante agua y una intensidad de luz moderada. En estas condiciones, su proceso fotosintético es muy eficiente, ya que los estomas pueden permanecer abiertos durante largos periodos, permitiendo un flujo constante de dióxido de carbono.

En este mecanismo se presenta la fotorrespiración, un proceso inútil que consume energía y carbono previamente fijado, liberando dióxido de carbono sin producir azúcares.



Fuente: GLOBAL BIOGEOCHEMICAL CYCLES, VOL. 17, NO. 1, 1006, doi:10.1029/2001GB001807, 2003

.....*La fotosíntesis puede seguir diferentes mecanismos.....*

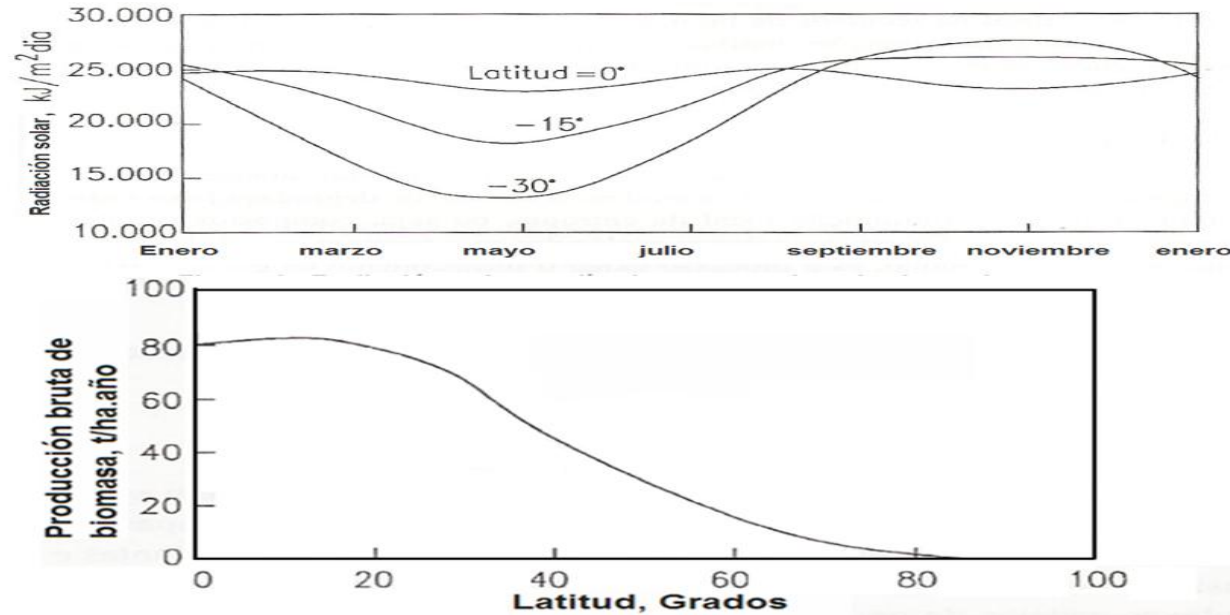
La vía fotosintética C4 representa una adaptación que minimiza la fotorrespiración, especialmente en ambientes calurosos y con mucha luz. Esta reacción produce un compuesto de cuatro carbonos, oxaloacetato, lo que le da nombre a la vía. Este compuesto de cuatro carbonos se convierte rápidamente en azúcares

Las plantas C4 también muestran una mayor eficiencia en el uso del agua, lo que significa que pueden producir más biomasa por unidad de agua transpirada. Esto permite que las plantas C4 prosperen en entornos con agua limitada. Las plantas C3, al no tener este mecanismo especializado, sufren una mayor reducción en la fotosíntesis bajo estrés hídrico debido al aumento de la fotorrespiración.



Fuente: GLOBAL BIOGEOCHEMICAL CYCLES, VOL. 17, NO. 1, 1006, doi:10.1029/2001GB001807, 2003

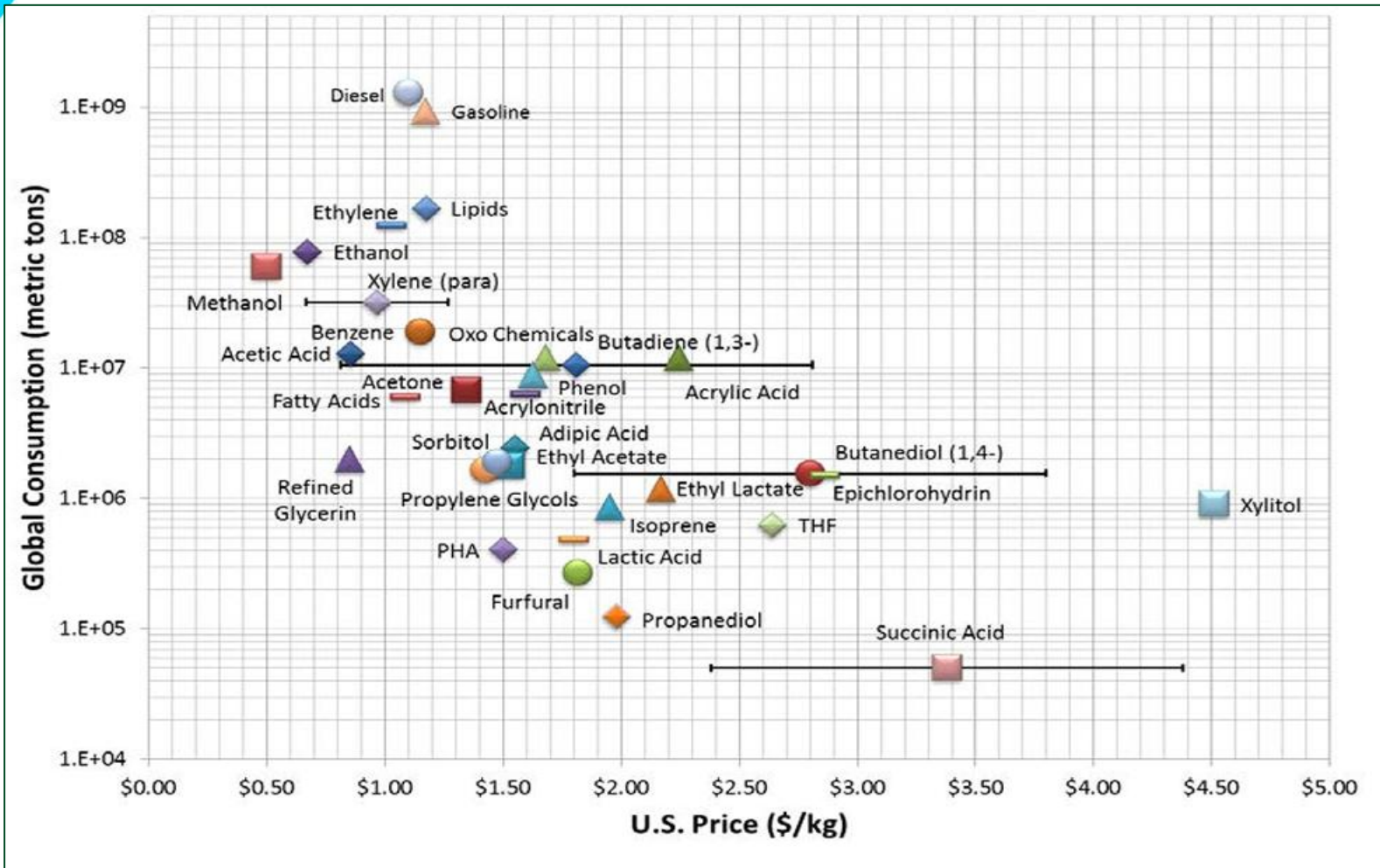
El potencial depende de factores ambientales



Las adaptaciones distintas de las plantas C3 y C4 influyen en su distribución global y en su presencia en varios ecosistemas. Las plantas C3 dominan las regiones más frías y húmedas, formando muchos bosques templados y praderas. Las plantas C4, con su eficiencia en altas temperaturas y condiciones de sequía, son prominentes en praderas tropicales y subtropicales, sabanas y regiones áridas. Esto muestra cómo diferentes estrategias fotosintéticas permiten a las plantas colonizar distintos nichos ecológicos.

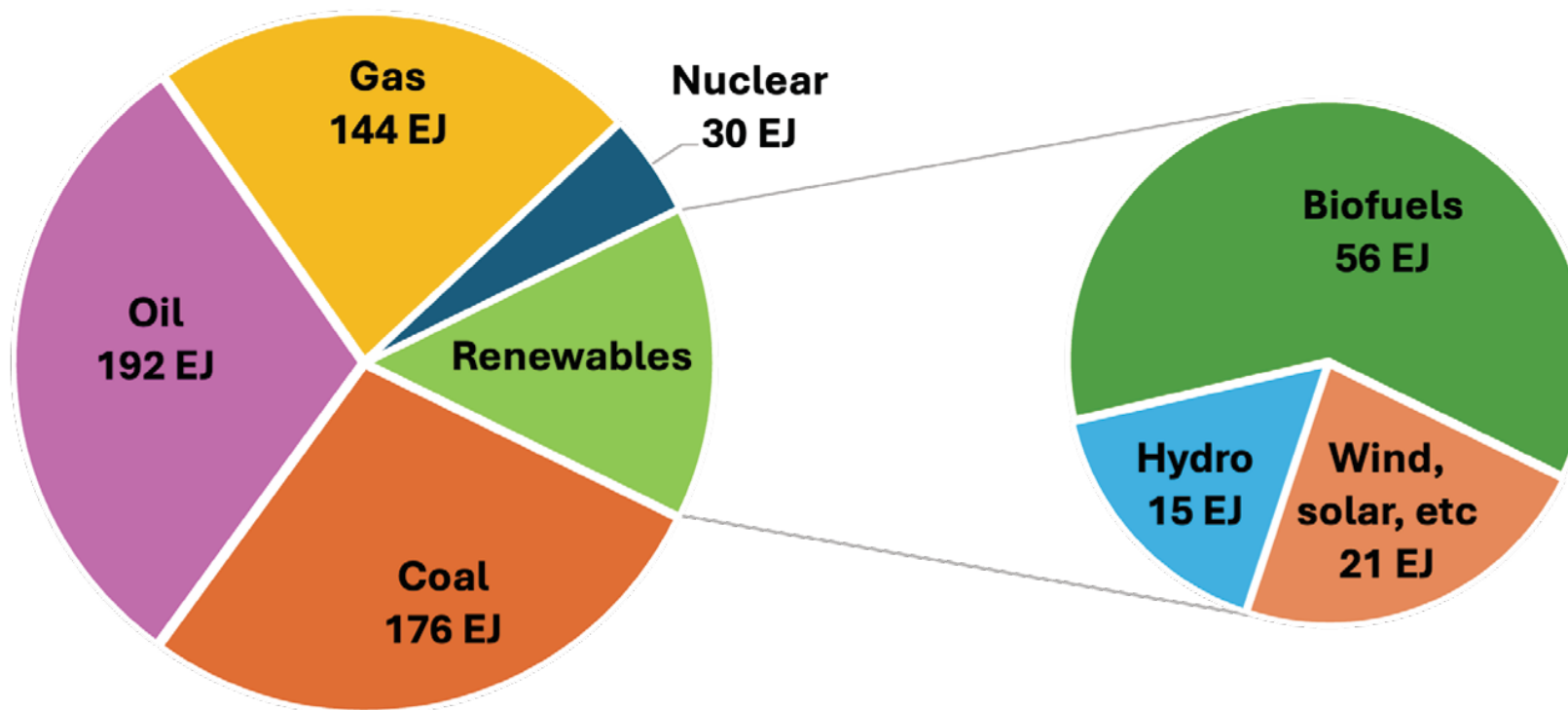
Consumo y precios unitarios para un conjunto de bioderivados en USA. (USD\$ 2025).

[Data and Tools](#) | [Bioenergy and Bioeconomy](#) | [NLR](#)



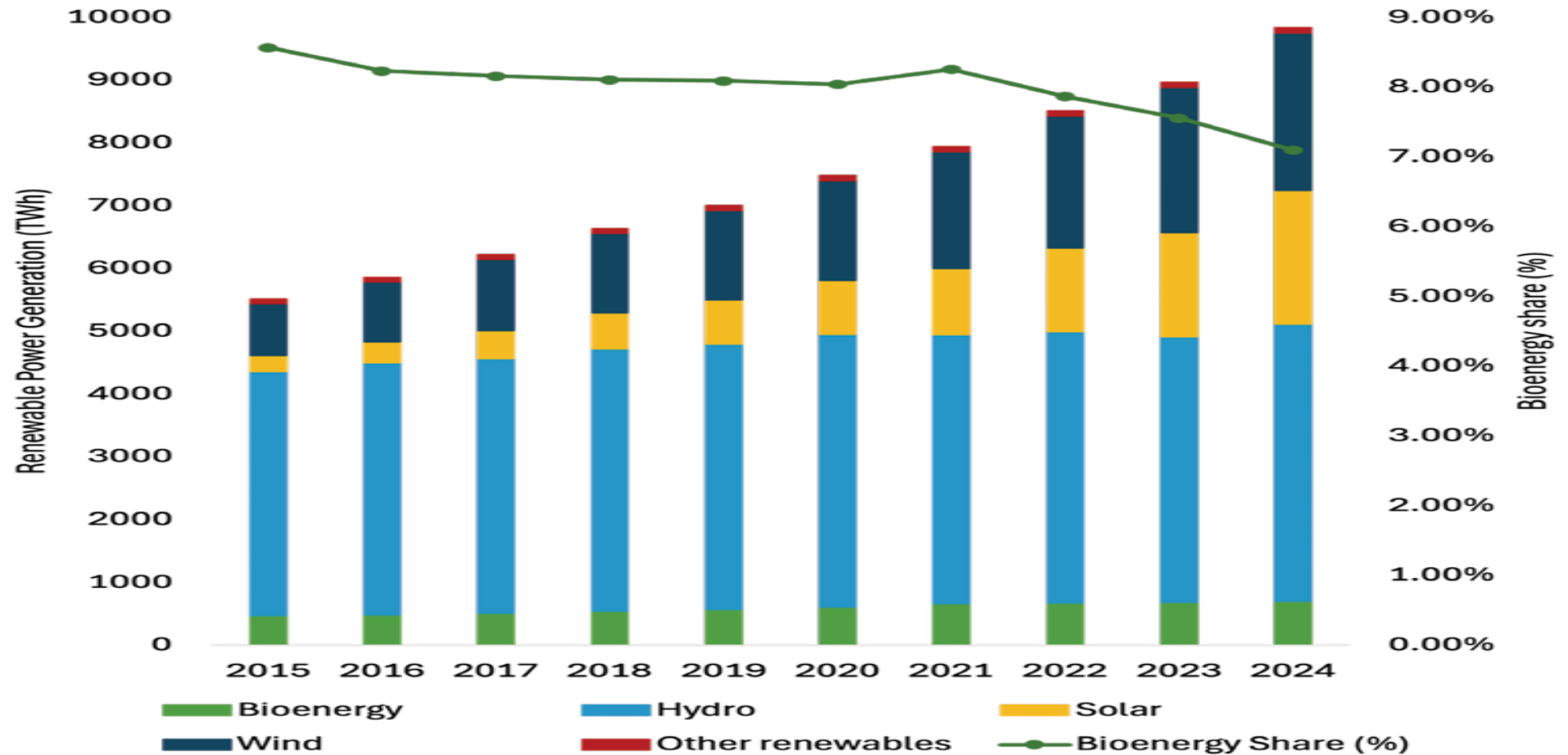
Mayores volúmenes, menores precios, una oportunidad para la biomasa y la biotecnología?

Suministro global de Energía, año 2023.



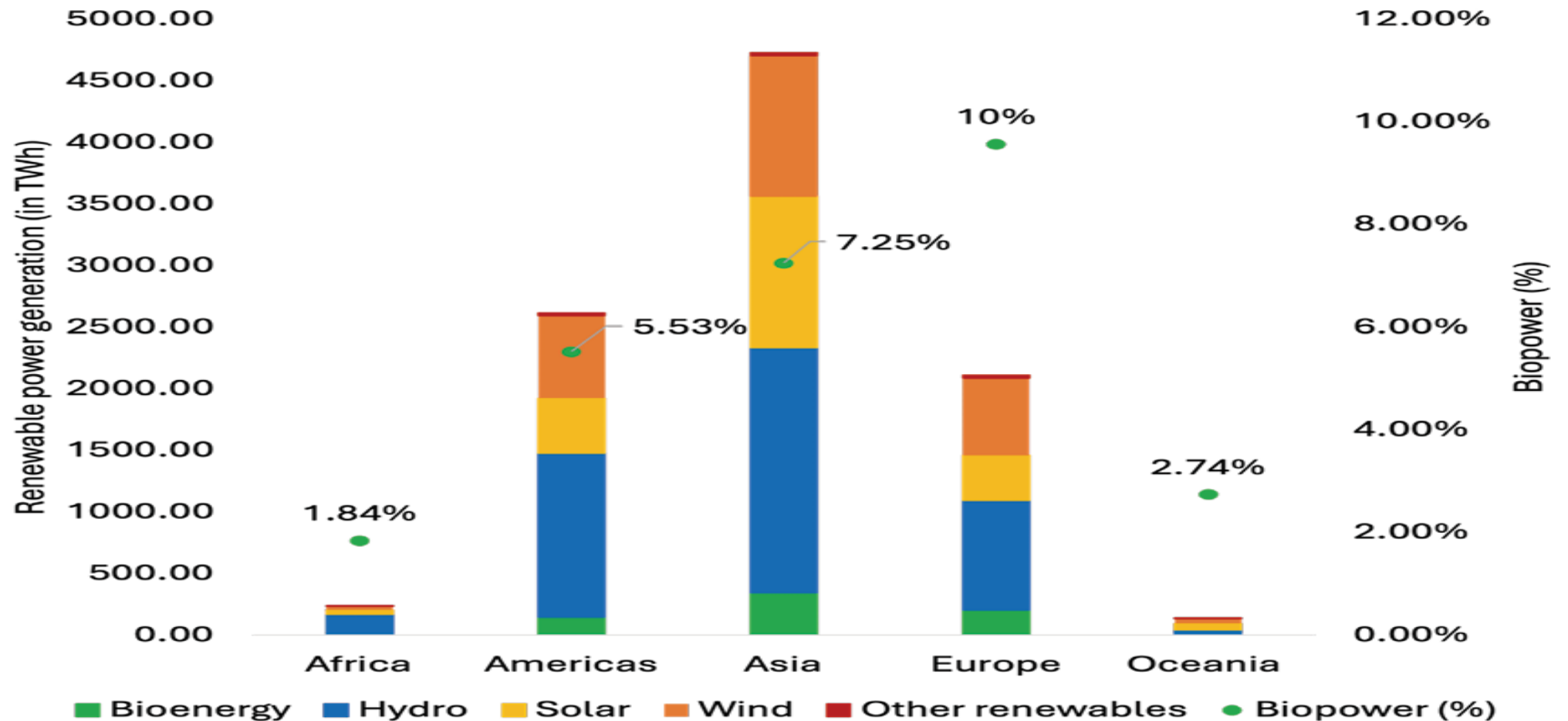
Fuente: (2025), 12th Edition. GLOBAL BIOENERGY STATISTICS REPORT

Generación global de energía eléctrica renovable, 2024



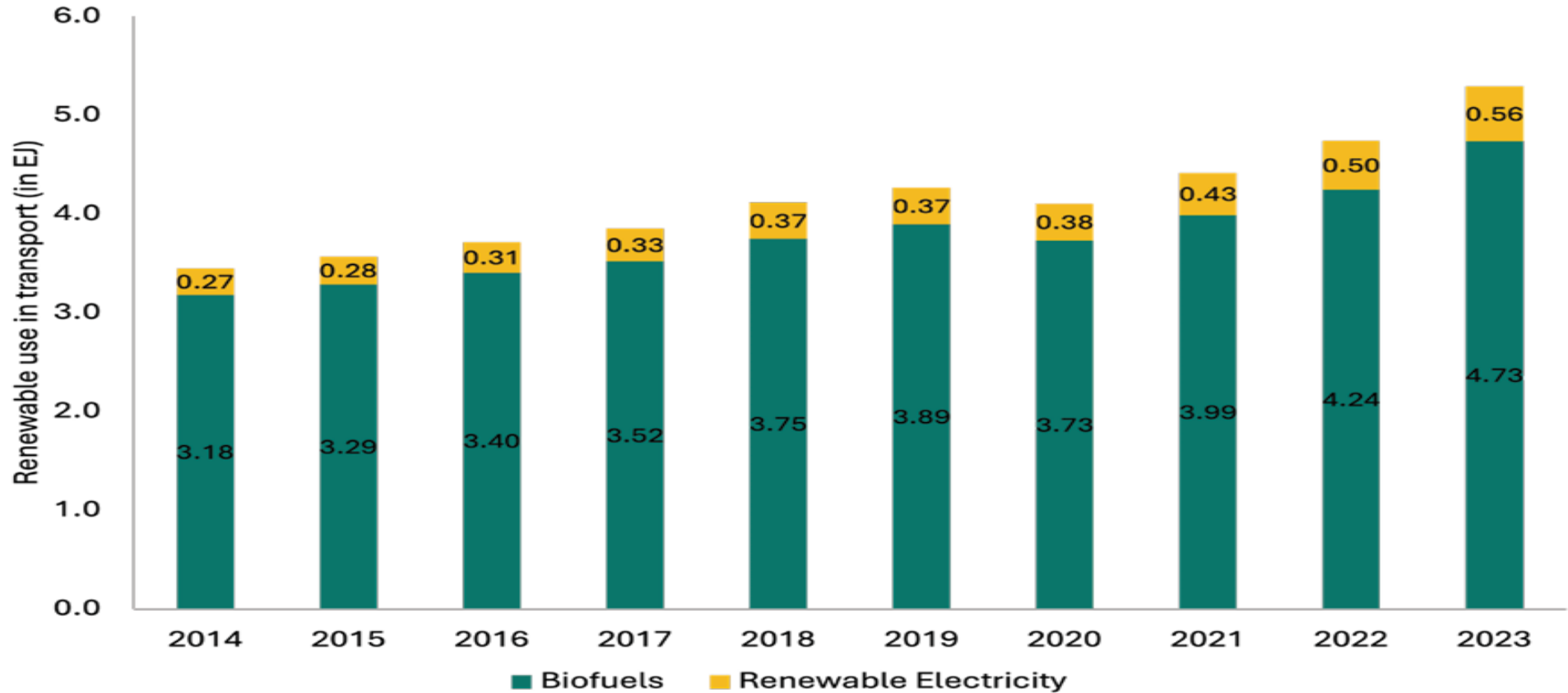
Fuente: <https://ember-energy.org/>

Generación eléctrica renovable por continentes, 2024



Fuente: <https://ember-energy.org/>

Uso de energía renovable en el sector transporte, 2023



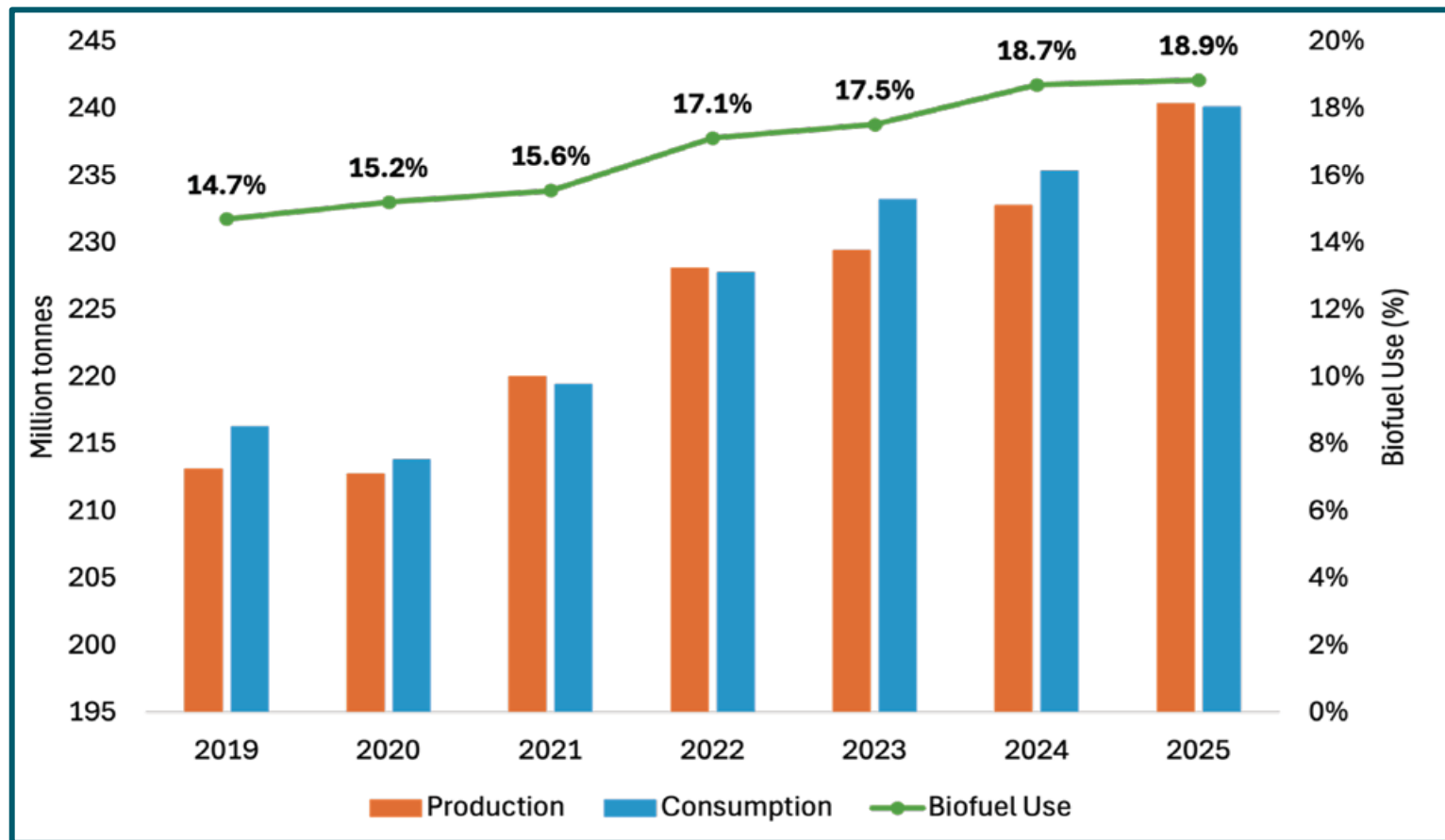
Fuente: (2025), 12th Edition. GLOBAL BIOENERGY STATISTICS REPORT

Uso de energía renovable en el sector transporte, por continentes. 2023

	Total	Biofuels	Renewable Electricity	Biofuels (%)
Africa	0.008	0.003	0.005	36
Americas	3.04	2.99	0.047	98
Asia	1.01	0.767	0.243	76
Europe	1.05	0.889	0.162	85
Oceania	0.047	0.034	0.013	72

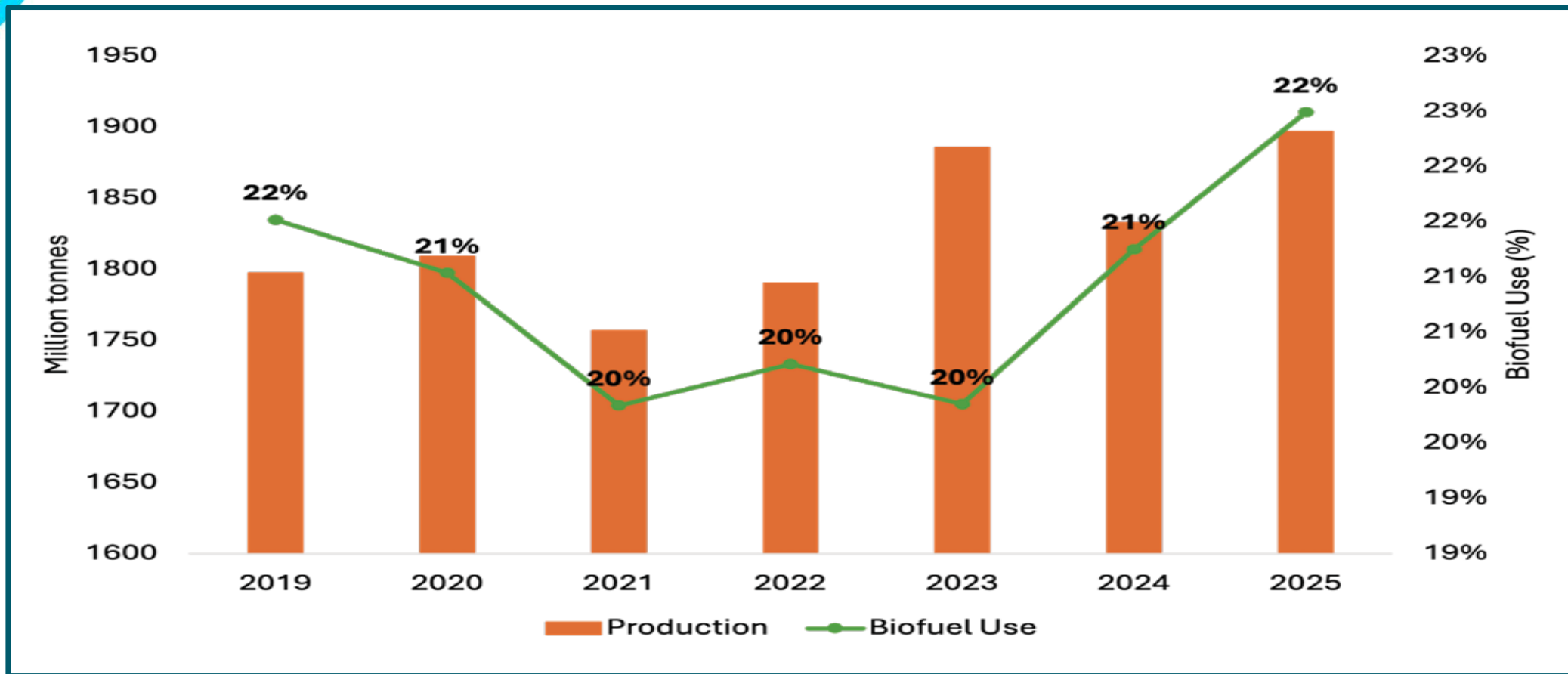
All values in EJ. Source: IEA

Producción global, consumo y uso para biocombustibles de los aceites vegetales



Fuente: OECD – FAO, 2026

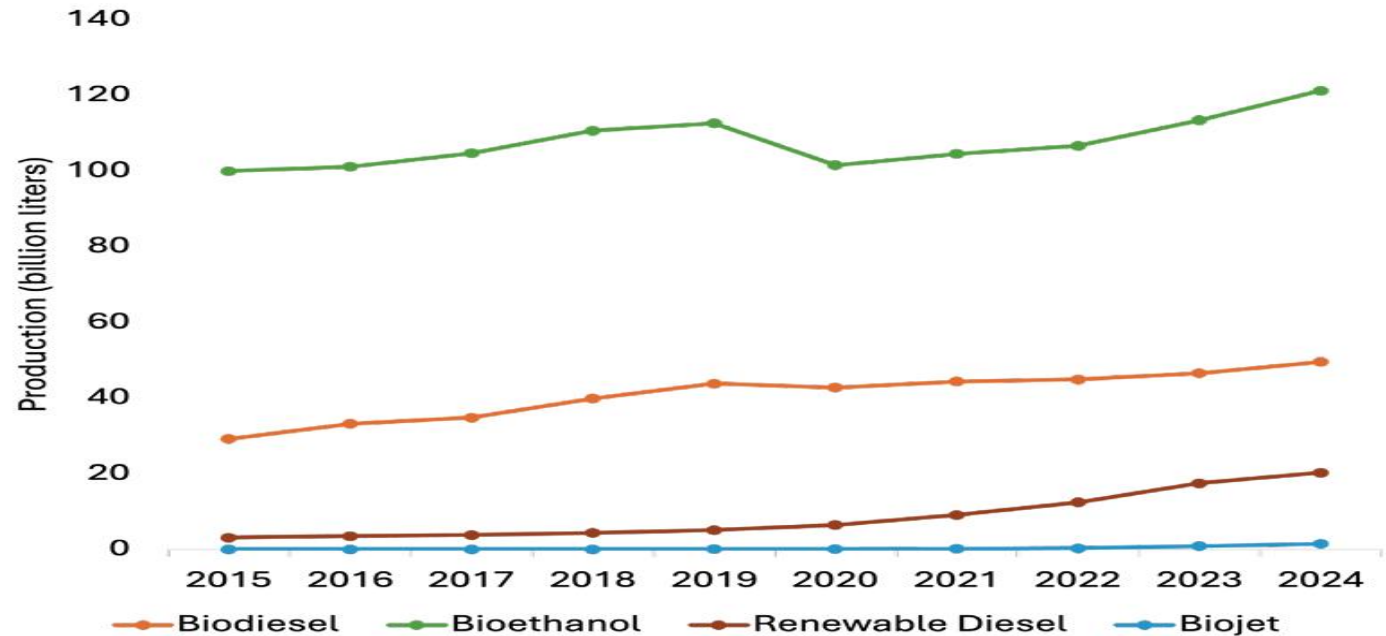
Producción global, consumo y uso para biocombustibles de la caña de azúcar, 2025.



Fuente: (2025), 12th Edition. GLOBAL BIOENERGY STATISTICS REPORT

Producción global de biocombustibles líquidos, 2024

- ❑ La producción de biocombustibles líquidos aumentó un 8% en 2024, continuando con la senda de crecimiento de la última década.
- ❑ El etanol es el biocombustible más producido, principalmente por el aporte de USA y Brasil.
- ❑ El biodiesel alcanzó un pico de 50 millones de litros y el diesel renovable multiplicó por 10 su producción de 2014.
- ❑ Comparativamente, el SAF cumple sus primeras etapas de introducción a los mercados.



Fuente: (2025), 12th Edition. GLOBAL BIOENERGY STATISTICS REPORT

Las barreras de mezcla (blending wall) para el uso del biodiesel presentan una dinámica creciente

- INDONESIA, principal productor de biodiesel planea B40 para 2026 y B50 para 2035.
- BRASIL establece B14 desde marzo 2024 y supera por tercer año consecutivo a USA en la producción total. B15 desde Agosto 1 2026.
- La producción de biodiesel en CHINA disminuyó un 18% en 2024, debido a medidas anti-dumping de la Unión Europea.



Advanced Biofuels USA, a nonprofit educational organization, is the immediate solution to reduce greenhouse gas emissions.

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Indonesia's 50% Biodiesel Blending Rate Takes Effect

Business News/Analysis Feedstocks Field/Orchard/Plantation Crops/Residues Indonesia Marketing/Market Forces and Sales Middle East Opinions Policy

July 03, 2026

Print This Article Share it With Friends

by Bernadette Christina (Reuters) Indonesia's new 50% biodiesel blending mandate took effect on Wednesday (July 1, 2026), requiring a fuel blend of half palm-based diesel and conventional diesel known as B50, even as stakeholders await a revised biodiesel allocation from the government.

POLICY NEWS

Jul 7, 2025

Brazil raises biofuel blending levels

Brazil's National Energy Policy Council (CNPE) approved raising the level of biofuels mixed into fossil fuels - a move towards petroleum self-sufficiency that was also celebrated by renewable energy lobbies after the government earlier hinted the blends would not be changed this year.

From August 1, the proportion of ethanol to be mixed in gasoline will rise to 30% from 27%, and the amount of biodiesel in diesel increases to 15% from 14%, Pietro Mendes, oil and gas secretary at the energy ministry, said during an event to announce the changes.

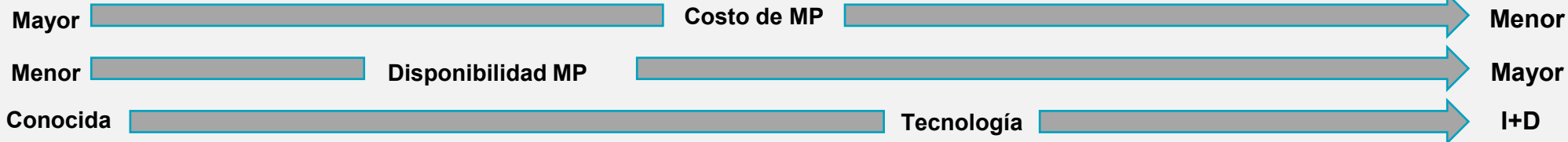
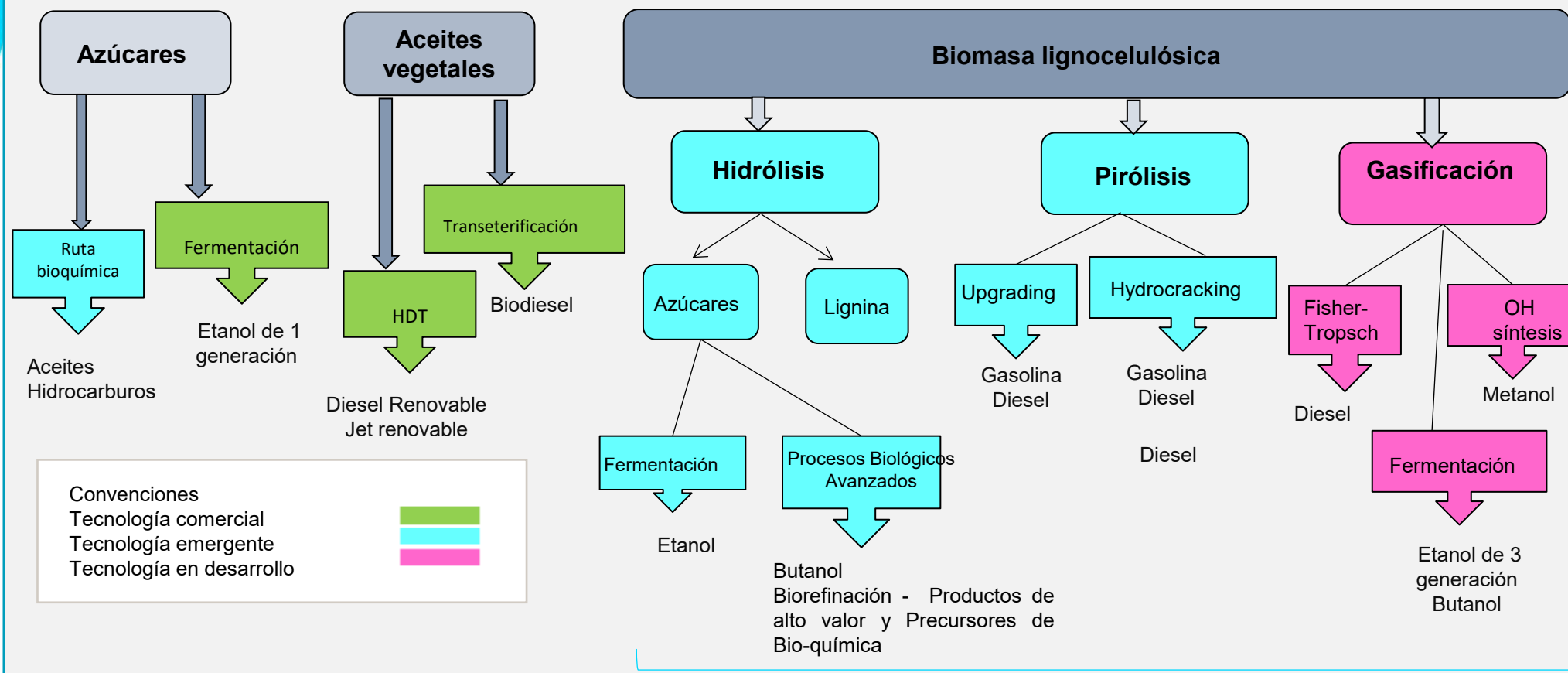
Mines and Energy Minister Alexandre Silveira also said at the event that the change in the biofuels mandate would make Brazil "gasoline self-sufficient for the first time in 15 years."

Earlier this year, the CNPE had decided to hold the biodiesel blend at 14% amid fears the proposed increase could push up food prices and damage the government's approval ratings, something industry groups disputed.



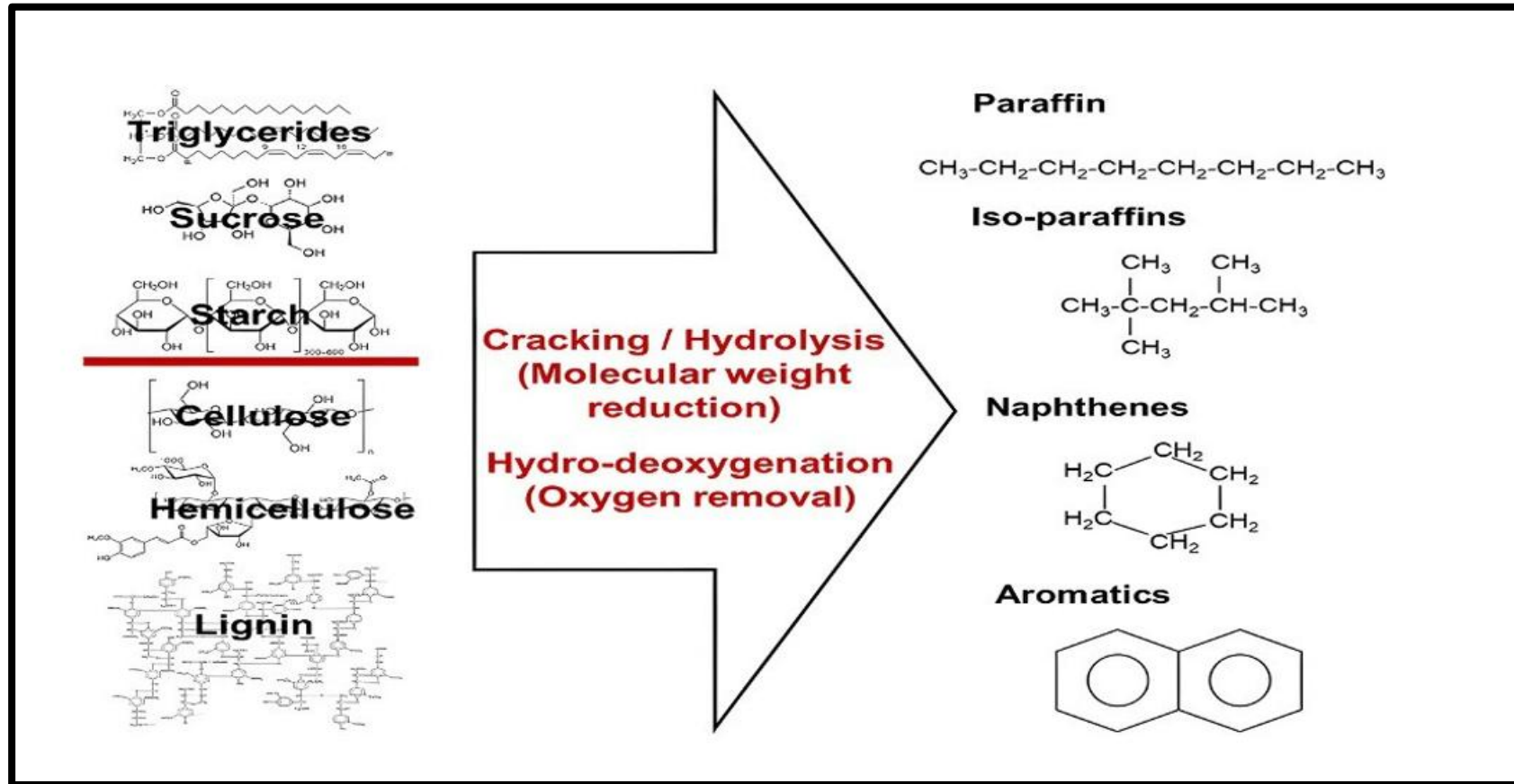
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RUTAS DE PROCESAMIENTO DE BIOMASA A BIOCOMBUSTIBLES



N° de Carbonos	C3-C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	>C20
PEB a 760 mm n-parafina																		
°C		36	69	98	126	151	174	196	216	235	253	270	287	302	316	329	343	
°F		97	156	209	258	303	345	384	421	456	488	519	548	575	601	625	649	
LPG	↔																	
Gasolina	↔																	
Nafta de precipitación	↔																	
Keroseno						↔												
Combustible JET						↔												
Diesel		No. de Carbonos				Isomeros				↔								
Gasóleos				4		2												• ↔
Ceras				8		18												↔ •
				12		355												
Residuos, Asfaltos				18		60,523										C ₄₄ ⁺ •		↔ •

Principios químicos de algunas rutas tecnológicas para la producción de biocombustibles a partir de biomasa



El potencial genérico de biomasa es diferente y particular

Caña de Azúcar

Una (1) tonelada de tallos cortados en campo

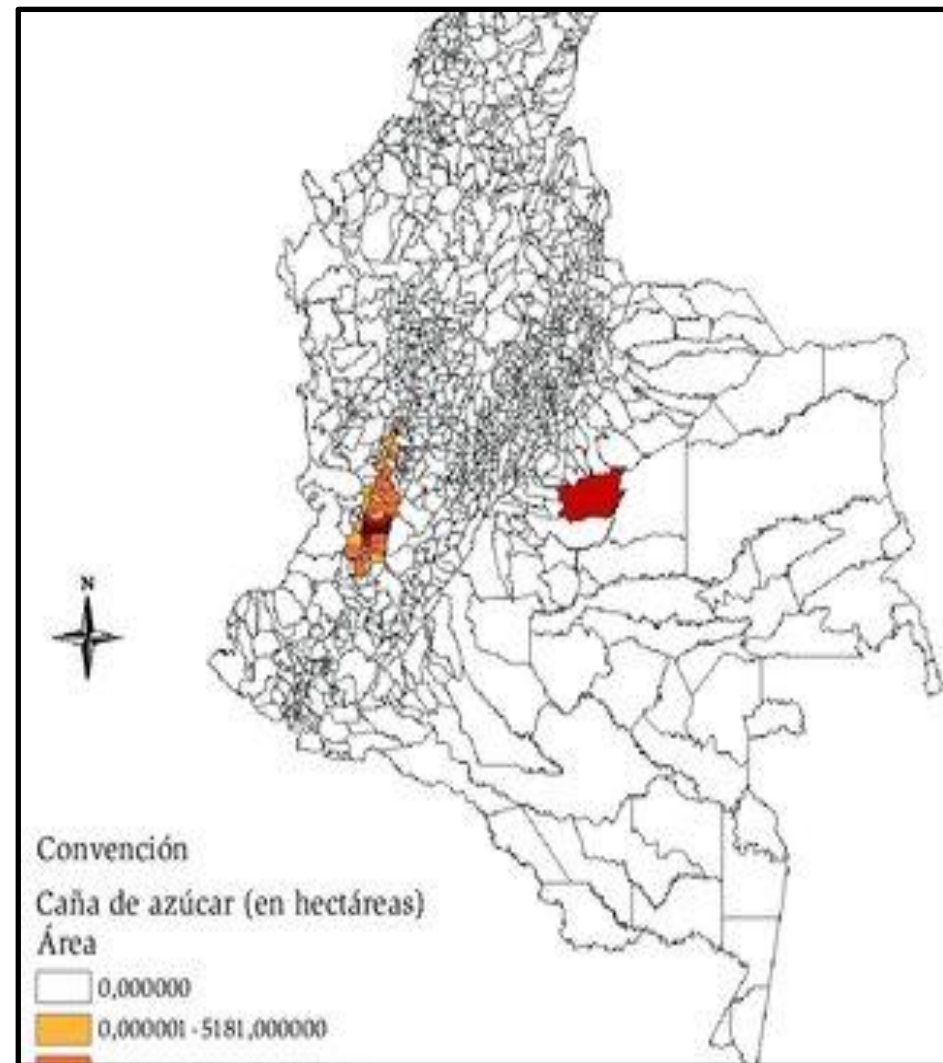
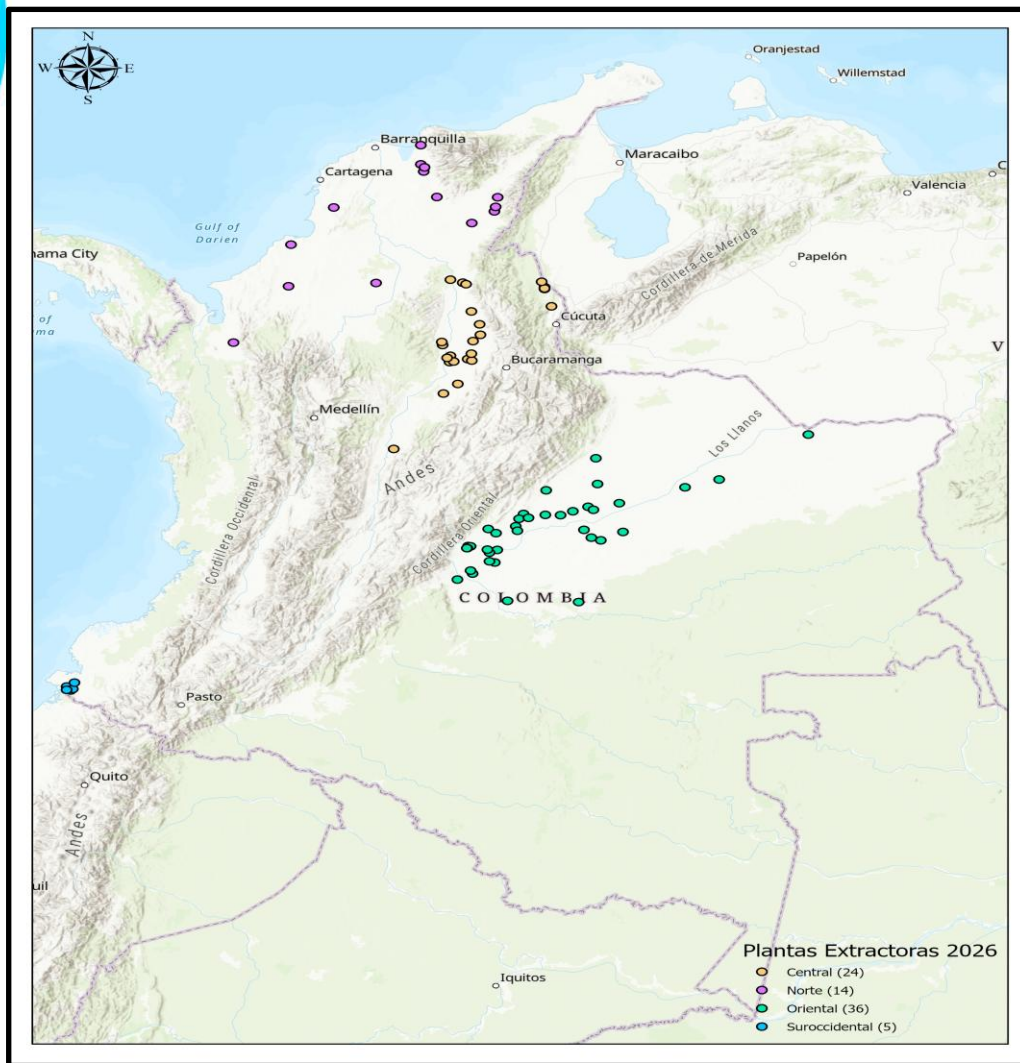
- ❖ 120 kgs de azúcar (o 62 kgs de etanol)
- ❖ 38 kgs de melazas
- ❖ 36 kilos de lodos y cachaza
- ❖ 250 kgs de bagazo
- ❖ 160 kgs de RAC (Residuos Agrícolas de Cosecha)

Palma africana

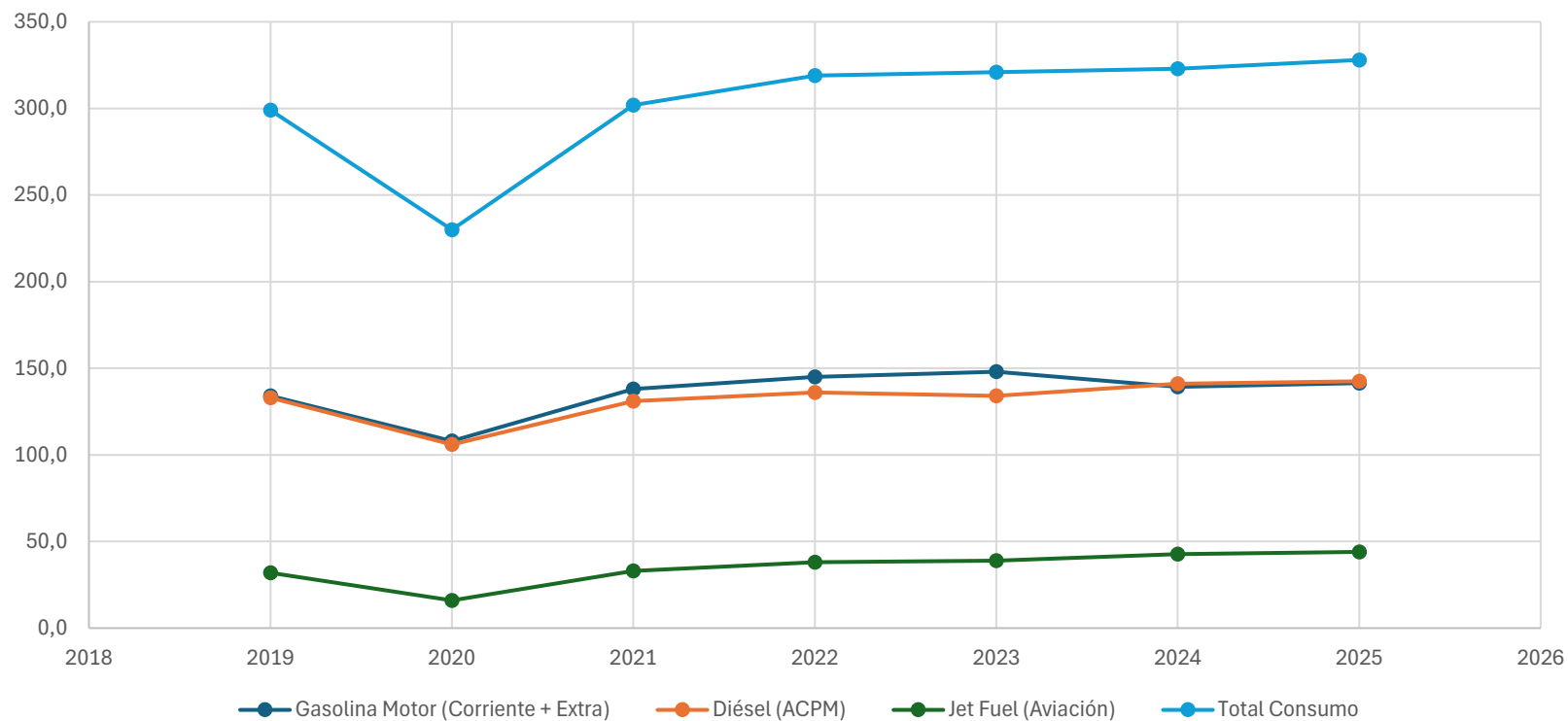
Una (1) tonelada de Racimo de Fruta Fresca

- ❖ 210 kgs de aceite
- ❖ 230 kgs de raquis
- ❖ 37 kgs de palmiste
- ❖ 150 kgs de fibras
- ❖ 60 kgs de cuezco

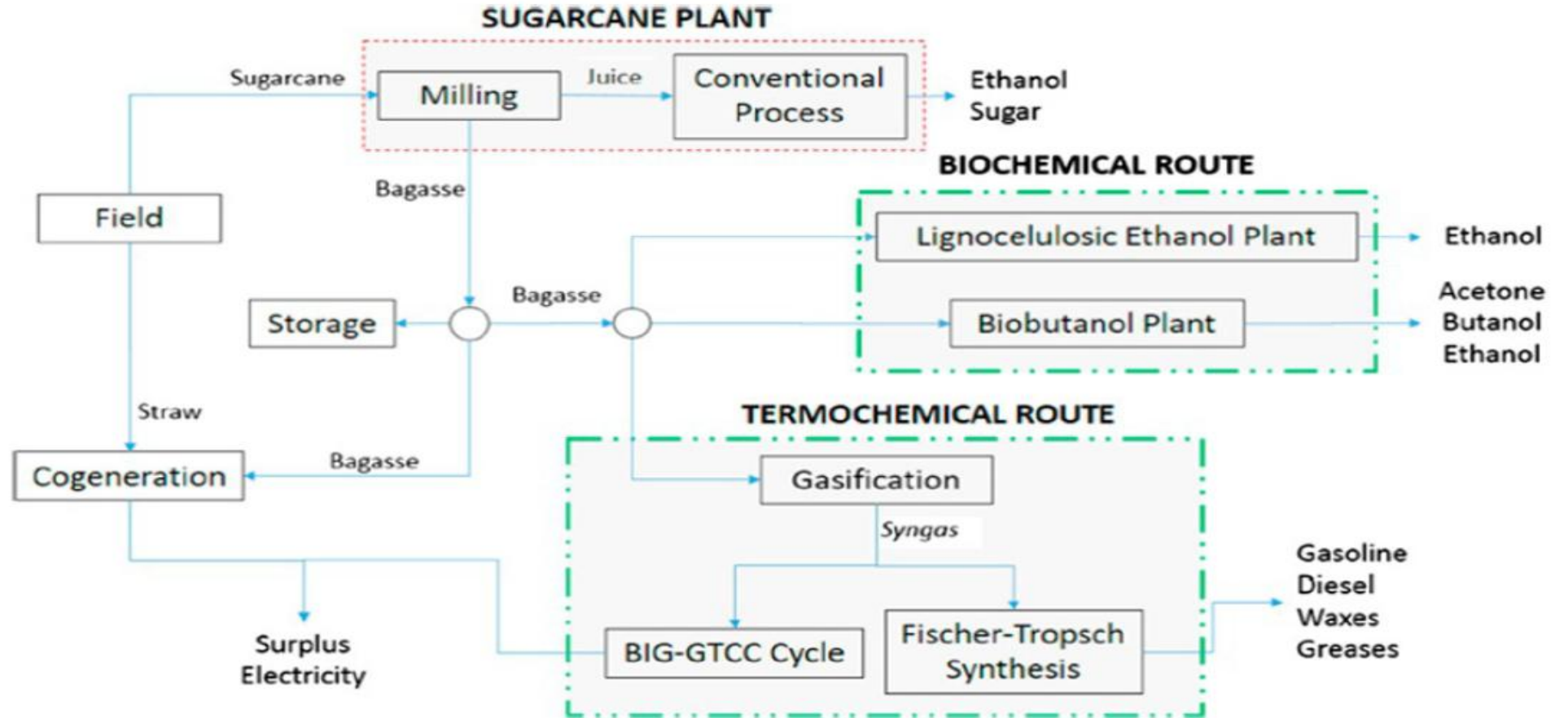
**La logística de
acopio y
recolección de
la biomasa es
un factor
crucial y
estratégico**



Evolución de la demanda de combustibles motor (KBD)



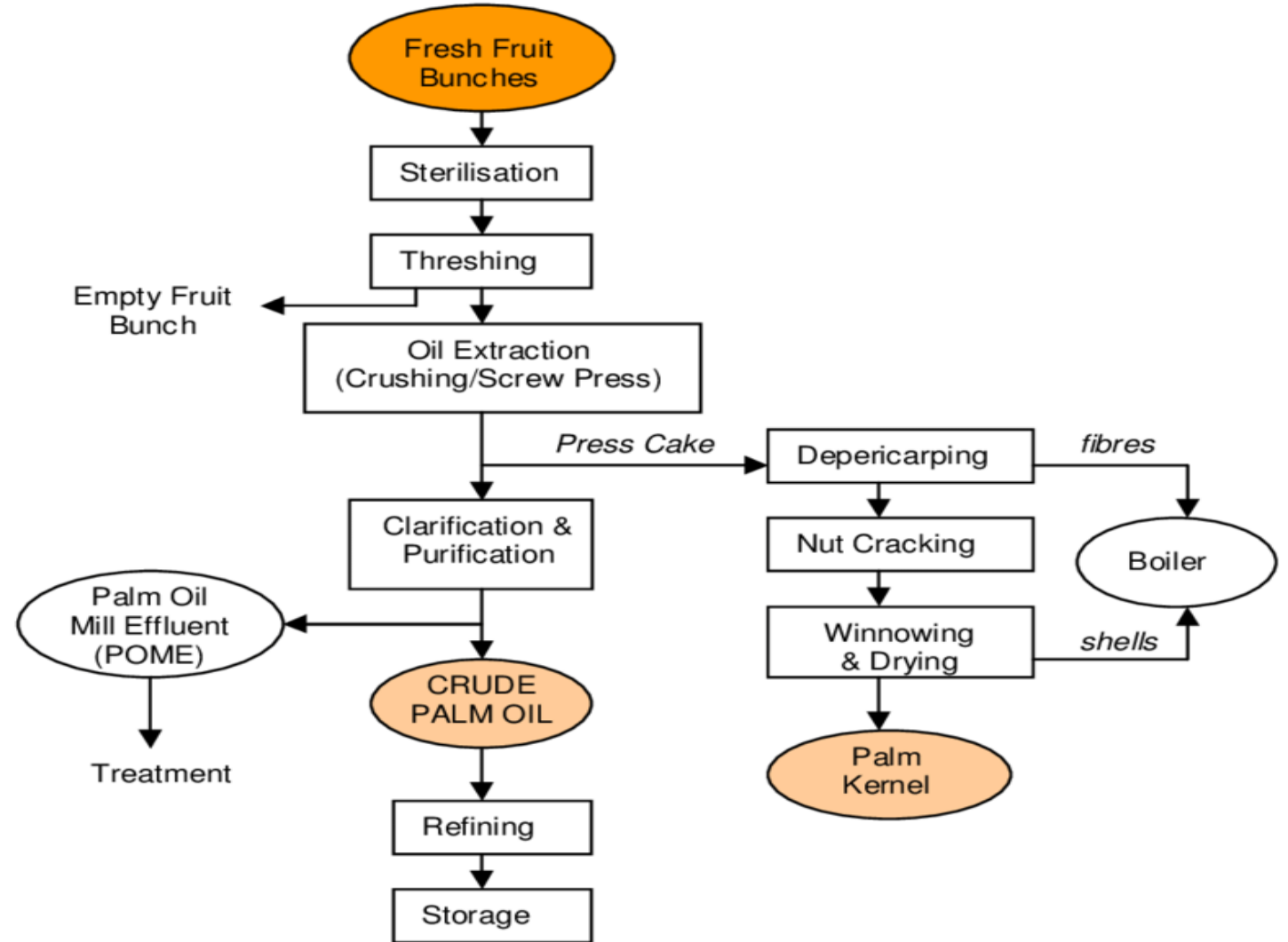
Potencial productivo de la cadena agroindustrial de la caña de azúcar



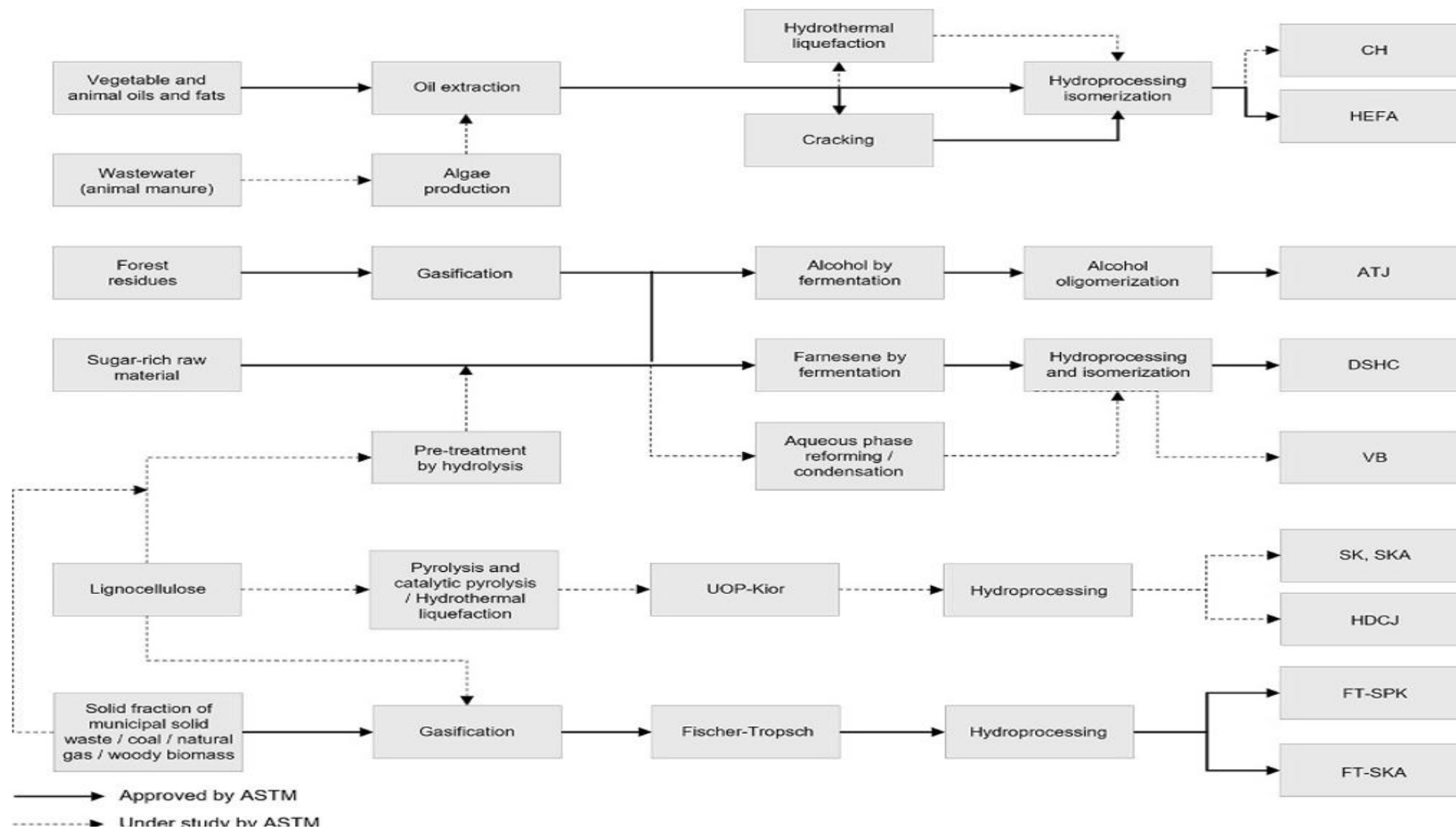
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graph LR
    SC_T[Sugar cane trash] --> MILLING
    SC[Sugar cane] --> MILLING
    MILLING --> Juice
    MILLING --> BT1[Bogasse + Sugar cane Trash]
    MILLING --> COG[COGENERATION (ELECTRICITY)  
RANKINE OR BIG/GT (STEAM)]
    COG --> Electricity
    COG --> Fermentation1[Fermentation]
    COG --> Acetic[Acetic Acid]
    COG --> Polymerization
    COG --> Separation[Separation Purification]
    Fermentation1 --> Juice
    Fermentation1 --> Fermentation2[Fermentation]
    Fermentation1 --> Fermentation3[Fermentation]
    Fermentation1 --> Stillage[Stillage]
    Acetic --> Evaporation
    Acetic --> Fermentation2
    Polymerization --> Separation
    Separation --> PLA[Poly(lactic Acid) Aliphatic Polyester]
    Separation --> Ethanol[Ethanol]
    Ethanol --> Polyethylene
    Ethanol --> Biobutanol
    Ethanol --> CellulosicBio[Cellulosic Bioethanol]
    Ethanol --> Biodiesel[Biodiesel Jet-fuel]
    Ethanol --> AnimalFeed[Animal feed]
    Ethanol --> Furfural
    Juice --> Evaporation
    Juice --> Fermentation2
    Juice --> Fermentation3
    Juice --> Stillage
    Evaporation --> Cristallization
    Cristallization --> Drying
    Drying --> Sugar
    Cristallization --> Distillation
    Distillation --> Dehydration
    Dehydration --> Ethylene
    Ethylene --> Polyethylene
    Dehydration --> Biobutanol
    Dehydration --> CellulosicBio
    Dehydration --> Biodiesel
    Dehydration --> AnimalFeed
    Dehydration --> Furfural
    BT1 --> Hydrolysis
    BT1 --> Enzymes
    BT1 --> Gosification
    Hydrolysis --> C6[Cellulose (C6)]
    C6 --> Hemicellulose[Hemicellulose (C5)]
    Hemicellulose --> Fermentation3
    Enzymes --> Saccharification
    Saccharification --> Fermentation2
    Fermentation2 --> Extraction
    Extraction --> Purification
    Purification --> Biobutanol
    Purification --> CellulosicBio
    Purification --> Biodiesel
    Purification --> AnimalFeed
    Purification --> Furfural
    Gosification --> GasCleaning[Gas Cleaning & Conditioning]
    GasCleaning --> Reformer[Reformer for Higher Hydrocarbons  
Shift reaction]
    Reformer --> ActivatedCatalytic[Activated Catalytic Synthesis]
    ActivatedCatalytic --> Biomethanol[Biomethanol Diesel Gasoline DME]
    ActivatedCatalytic --> Furfural
    
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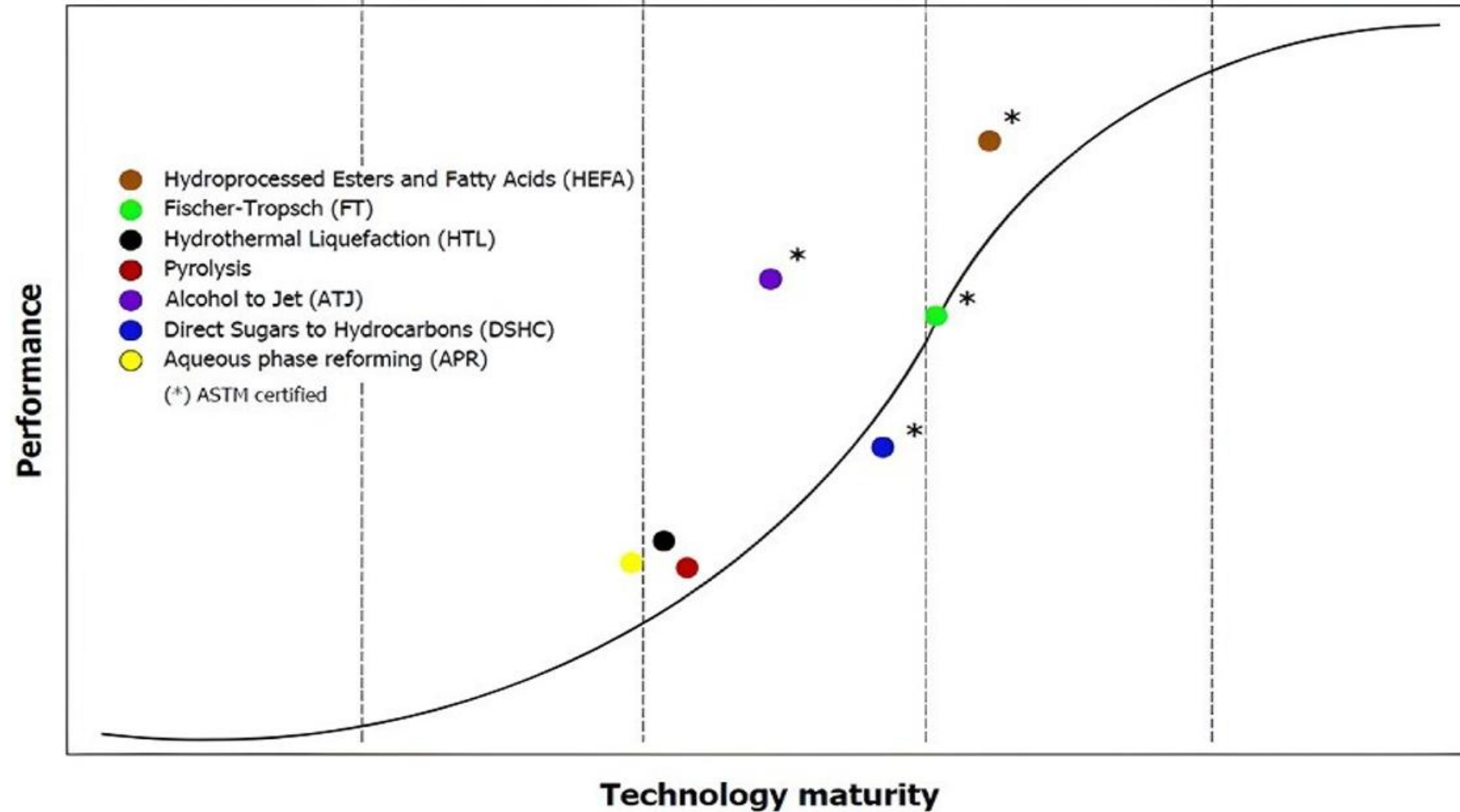
**La
concentración
de potencial de
biomasa es
fundamental
para abordar la
escala de
biorrefinería**



Rutas tecnológicas para la producción de SAF a partir de la biomasa



Clasificación del nivel de madurez para algunas tecnologías para producir SAF



Comparación de procesos representativos para la producción de SAF

Process	Edible biomass		Non-food biomass	
	HEFA	ATJ	Gasification + FT	PTL
Material	Waste cooking oil Animal and vegetable oils and fats	Fermentation ethanol (Biomass gasification process is being developed)	Biomass	Biomass, Waste DAC
Overview	Hydrocracking from oils and fats	Modification from fermentation ethanol	Gasifier + FT synthesis from woody biomass	H₂ and CO are generated from electrolysis and Water Reverse Shift.
State	Commercialized	Commercialized	Demonstration plant	Demonstration plant
Feature	- Low cost - Heat and H₂ are necessary to input	- Low cost about fermentation - Heat and H₂ are necessary to input	- Higher cost - Low LCA due to biomass using for the process	- Depend on electricity cost and carbon resources
LCA result [31]	13.9 – 60.0 gCO₂/MJ Fuel cultivation : 45% Fuel production : 45% Others : 10%	24.0 – 55.8 gCO₂/MJ Fuel cultivation : 45% Fuel production : 45% Others : 10%	5.2 – 12.2 gCO₂/MJ Fuel cultivation : 40% Fuel transportation : 40% Others: 20%	(Not estimated)

Fuente: "An entrained flow biomass gasification technology with the fluidized bed concept for low-carbon fuel production". Keigo Matsumoto. Ecosystems Research Department, Research & Innovation. Center, Mitsubishi Heavy Industries, Ltd. 12, Nishikicho, Naka-ku, Yokohama, Kanagawa, 231-8715, Japan. Applications in Energy and Combustion Science 20 (2024) 10.02.92

Algunos indicadores de desempeño de tecnologías más viables para la producción de SAF

TECNOLOGIA	CONVERSION A SAF	CONSUMO DE H2	CONSUMO EE	EXCEDENTE EE	CONSUMO H2O
	TON SAF/TON BIOMASA	TON H2/TON SAF	kWh/TON SAF	kWh/TON SAF	TON H2O/TON SAF
ATJ	11%	0,017	5519	328	39
HEFA	59%	0,073	33		9
G-FT	11%	0,002	3429	1012	150

Fuente: Biomass and Bioenergy 145 (2021) 105942

LA DESCARBONIZACION DE LA ECONOMÍA

- ❑ Mitigar y reducir la emisión de gases de efecto invernadero es una etapa inicial necesaria para la transición energética. Existe un portafolio tecnológico para este objeto, pero no necesariamente es una actividad viable desde el punto de vista ambiental y financiero.
- ❑ **CCUS** = Carbon Capture Use and Storage
- ❑ **Captura** del carbono desde corrientes existentes. Ejemplo: Flue gases o gases de chimenea luego de la combustión. O la separación del CO2 directamente del aire.
- ❑ **Uso:** Utilización del carbono como insumo químico para la producción de compuestos ya existentes en el mercado. Ejemplo: Carbonato de calcio precipitado
- ❑ **Storage:** Almacenamiento geológico, en el subsuelo. Ejemplo: Inyección en pozos petroleros agotados.

Combustibles sintéticos

El combustible sintético es un compuesto líquido o gaseoso creado a partir de fuentes que no son petróleo, diseñado para imitar los combustibles convencionales y al mismo tiempo ofrecer posibles beneficios neutros en carbono.

	E-FUELS	PASSENGER CARS	HEAVY DUTY	MARITIME	AVIATION	OTHER SECTORS (NON TRANSPORT)
Gas	e-methane (CH ₄)	X	XX	XX		XXX
	e-hydrogen (H ₂)	XX	XX	X		X
Liquid	e-ammonia (NH ₃)	X	X	XXX		
	e-methanol (CH ₃ OH)	XX	X	X		
	e-DME/e-OME	X	XX	XX		
	e-gasoline	X				
	e-diesel	X	XXX	XX		
	e-jet				XXX	

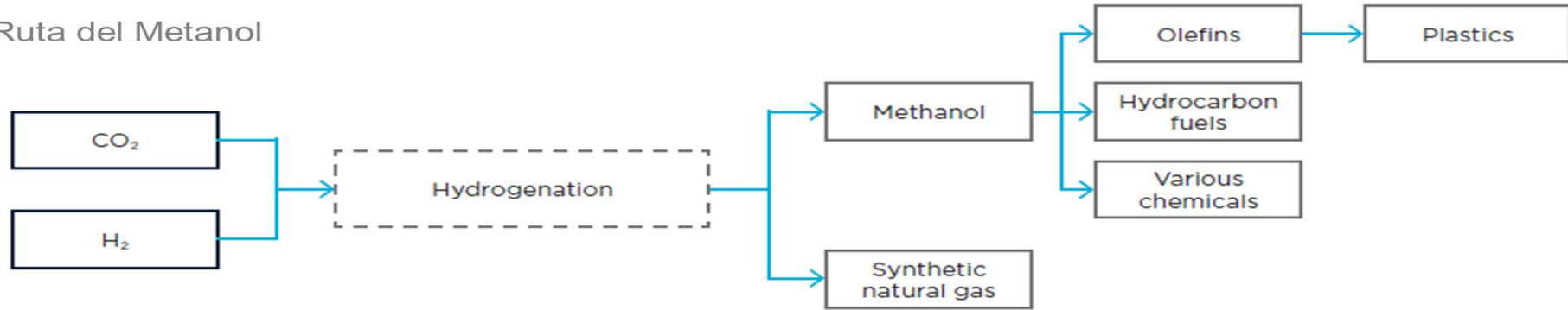
*X's are an initial estimate of the relative potential role of different e-fuels in transport segments (no 'X' = no envisaged potential). Green = primary use; blue = secondary use; yellow = minority use. 'Other sectors' include industry, building and power.

Table 2: Qualitative overview of e-fuels

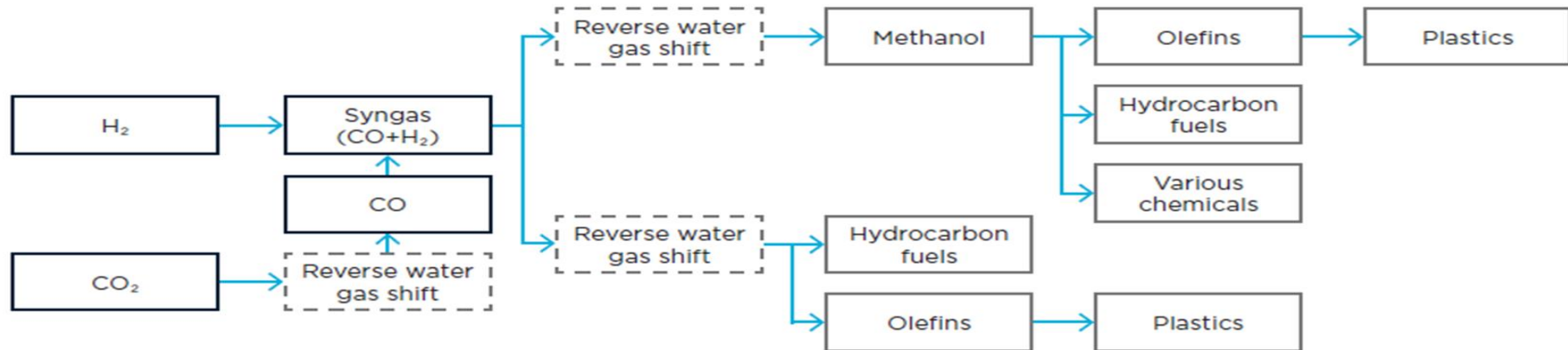
	E-FUELS	LOWER HEATING VALUE (LHV), MJ/kg / MJ/litre	STORAGE	ADDITIONAL INFRASTRUCTURE	POWERTRAIN DEVELOPMENT
Gas	e-methane	46.6 / 0.04	Medium ^a	No	No
	e-hydrogen	120 / 0.01	Difficult	Yes	No ^b
Liquid	e-ammonia	18.6 / 14.1	Easy	Yes	Yes
	e-methanol	19.9 / 15.8	Easy	No	Yes
	e-DME	28.4 / 19.0	Easy	Yes	Yes
	e-OME	19.2 / 20.5	Easy	Yes	Yes
	e-gasoline ^c	41.5 / 31.0	Easy	No	No
	e-diesel ^c	44.0 / 34.3	Easy	No	No
	e-jet ^c	44.1 / 33.3	Easy	No	No

El uso del CO₂ puede tener dos alternativas principales.

Ruta del Metanol

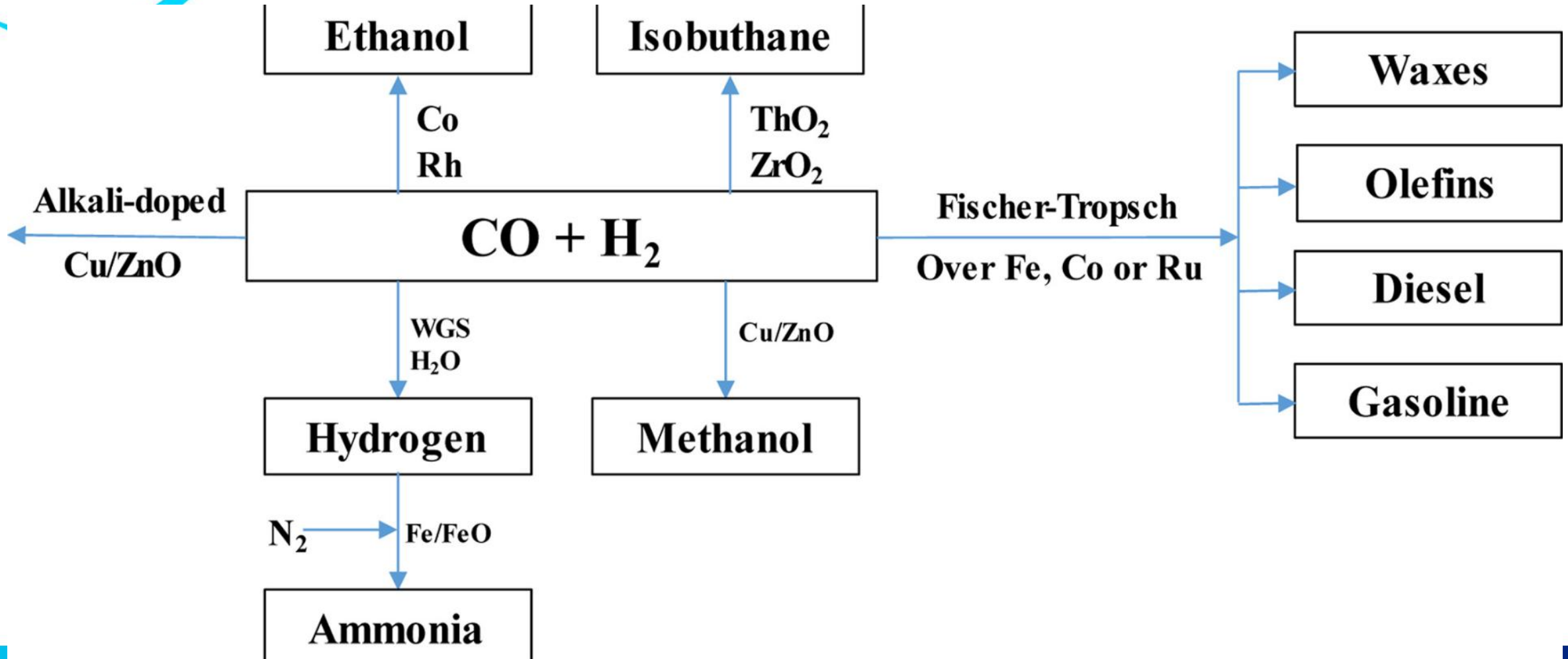


Syngas route

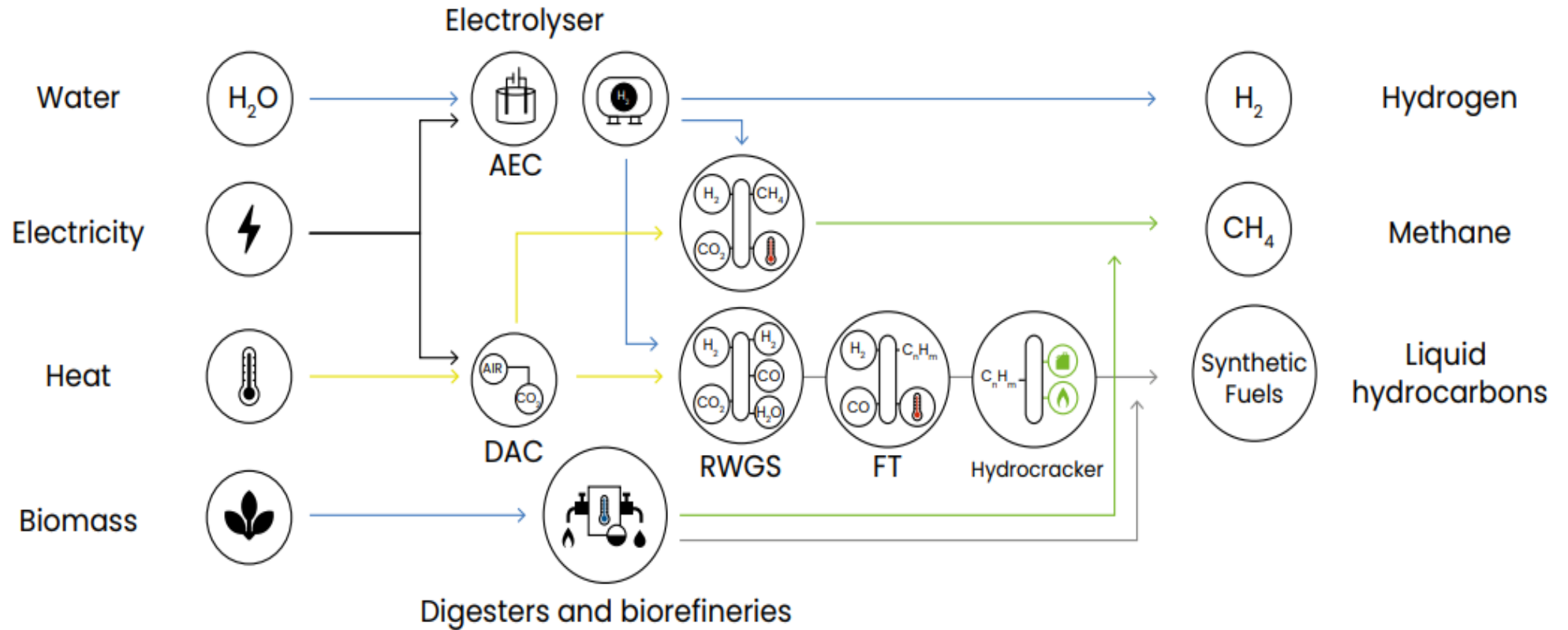


El CO₂ proveniente de la biomasa promueve que el ciclo de vida de los productos finales sea carbono negativo

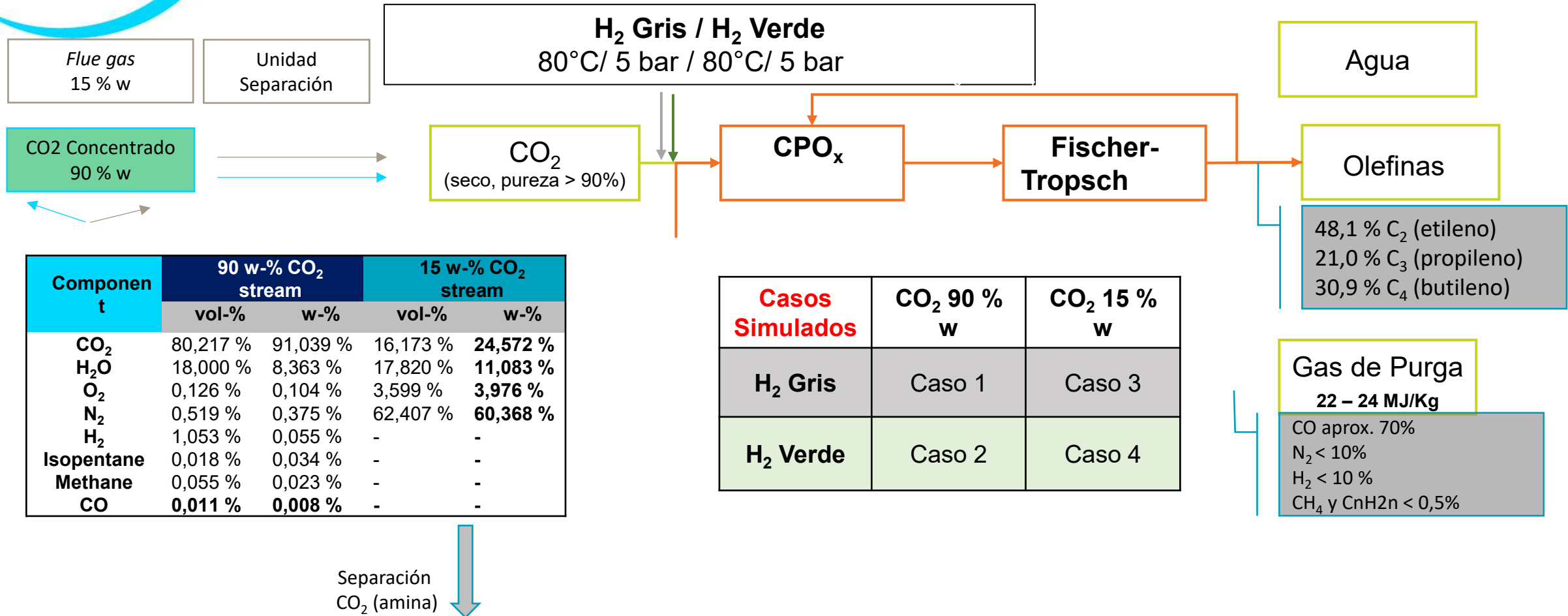
Las posibilidades cinéticas del Syngas



Esquema conceptual para la producción de e-fuels

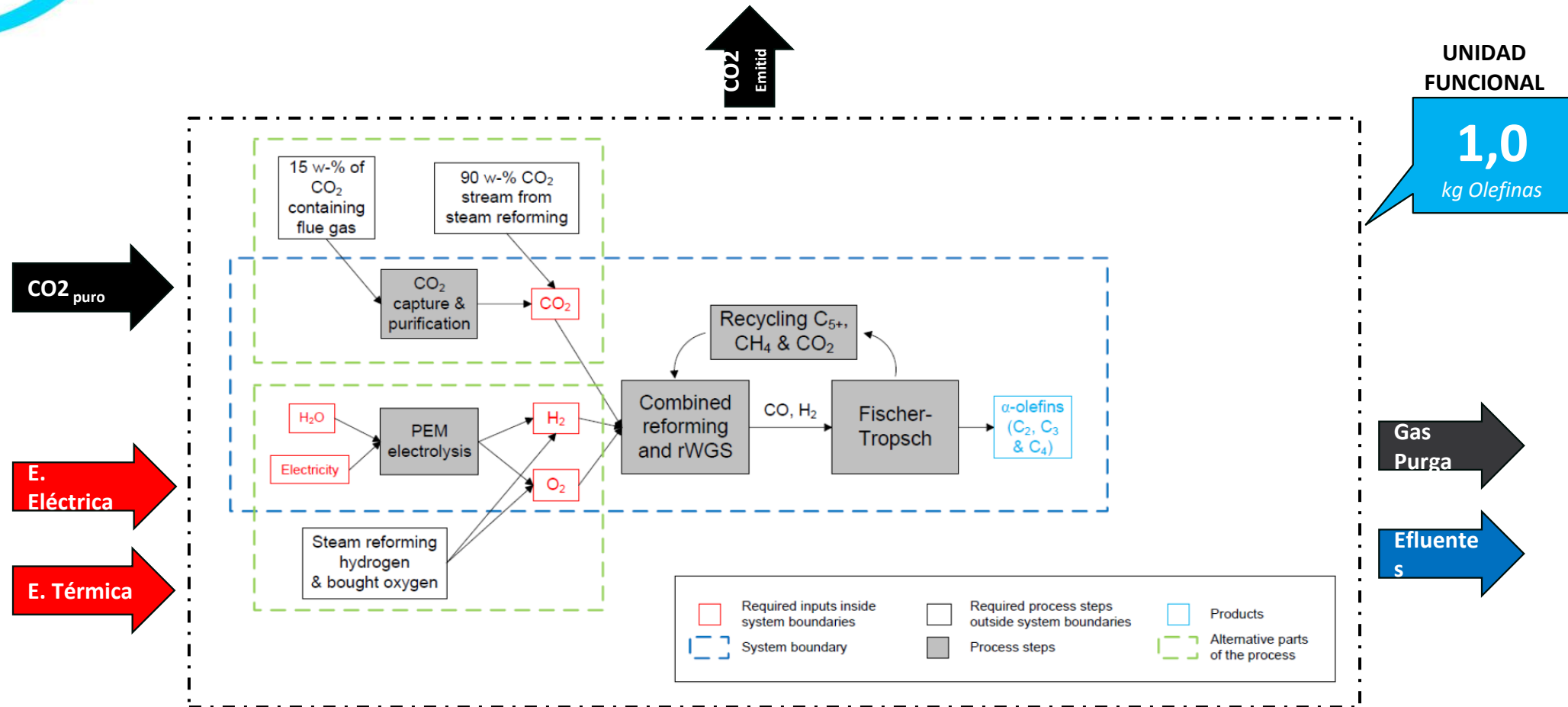


CCUS = Carbon Capture Use and Storage. Uso para olefinas sintéticas



15,06 t/h CO₂

Sin embargo, sintetizar nuevos compuestos a partir del CO₂ separado y concentrado, puede generar nuevas emisiones debido a los consumos de energía adicionales



Gracias

A stylized sunburst or starburst graphic composed of several elongated, rounded rectangular segments radiating from a central point. The segments are in various shades of blue, with the outermost ones being a lighter blue and the inner ones being a darker blue. The graphic is positioned on the right side of the slide, partially overlapping the blue background.

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